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CNC CHARLESTON
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RESOURCE CONSERVATION AND RECOVERY ACT FACILITY INVESTIGATION ZONE K NAVAL ANNEX OFF-SITE GROUNDWATER SAMPLING STRATEGY CNC CHARLESTON SC
9/5/2000
ENSAFE INC.

ZONE K – NAVAL ANNEX RCRA FACILITY INVESTIGATION OFF-SITE GROUNDWATER SAMPLING STRATEGY CHARLESTON NAVAL COMPLEX CHARLESTON, SC

SOUTHDIV CONTRACT
NUMBER: N62467-89-D-0318

Prepared for:

DEPARTMENT OF THE NAVY
SOUTHERN DIVISION
NAVAL FACILITIES ENGINEERING COMMAND
NORTH CHARLESTON, SOUTH CAROLINA

Prepared by:

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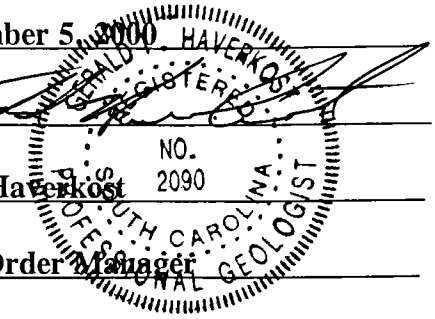
The Contractor, EnSafe Inc., hereby certifies that, to the best of its knowledge and belief, the technical data delivered herewith under Contract No. N62467-89-D-0318 is complete, accurate, and complies with all requirements of the contract.

Date: September 5, 2000

Signature:

Name: Todd Haverkost

Title: Task Order Manager



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1.0 INTRODUCTION

Groundwater quality in the surficial aquifer at the Naval Annex has been extensively evaluated, primarily as part of the Solid Waste Management Unit (SWMU) 163 and SWMU 166 chlorinated solvent plume investigations. SWMU 163 is identified in the RCRA permit issued to the Navy by South Carolina and EPA as a "Concrete Pit" that has been used as a less than 90 day hazardous waste storage area. A 1963 map shows the concrete pit was originally used as a coal storage bin. Releases from this unit have resulted in a shallow, discrete tetrachloroethene (PCE) plume in the west-central portion of the zone that has an average radius of 25–30 feet based on the pattern of clean points surrounding the highest concentration. SWMU 166 is identified as the "Automobile Service Rack" based on a review of historic maps that indicated an auto service rack was proposed for this area at one time. Further review of additional maps obtained after the SWMU designation was given have indicated that the area was a fenced compound used for "oil storage" circa 1963. Releases from this area have resulted in a dissolved phase trichloroethene (TCE) plume that fully penetrates the surficial aquifer and generally extends from the center of the zone to its eastern boundary. Migration of the contamination from SWMU 166 is hydraulically influenced by a drain system beneath I-26. The source areas for both SWMU 163 and SWMU 166 are shown on Figure 1 along with all of the groundwater data points installed to date.

Sampling efforts associated with both of these sites identified low levels of solvent contamination upgradient of the sites in the deeper portion of the surficial aquifer suggesting another source is present. In November 1999, a RCRA Facility Investigation (RFI) Work Plan Addendum was submitted to SCDHEC and EPA which outlined an approach for investigating the deeper contamination. Grid-based vertical groundwater profiling was performed in December 1999 in areas considered to be upgradient of both sites and in some instances side gradient to SWMU 163. The purpose was to further evaluate the deep detections. Grid-based sampling points (200 ft by 200 ft) throughout the western portion of the zone revealed consistent detections at 10 of the 12 locations. This includes detections at locations GDKGP011, GDKGP012, and GDKGP013

LEGEND:

- 166008 — SHALLOW MONITORING WELL LOCATION
- 16608D — DEEP MONITORING WELL LOCATION
- 16303M — MULTI-LEVEL VERTICAL PROFILE MONITORING WELL LOCATION
- 166GP003 — GROUNDWATER DPT SAMPLE

REVISIONS		
Rev Number:	Rev Date:	Rev By:
Rev Number:	Rev Date:	Rev By:
Rev Number:	Rev Date:	Rev By:
Rev Number:	Rev Date:	Rev By:
Rev Number:	Rev Date:	Rev By:

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FIGURE 1
GROUNDWATER MONITORING WELL LOCATION MAP
NAVAL ANNEX

Dr by: W. FAULK		Tr by: –	
Ck by: T. HAVERKOST		Appr by: T. HAVERKOST	Sheet 1
Date: 08/16/00		DWG Name: 2911C107	Of 1

along the northwestern property boundary. The highest concentrations were detected in deep groundwater at sample point GDKGP011. The data from the December 1999 sampling event is included in Appendix A. The source of this contamination has not been identified and will require sampling outside the boundary of the Naval Annex. The data from the vertical profile sampling efforts in December 1999 are presented in tabular form and graphically in Appendix A. The data was combined with representative data from other groundwater sampling events from the RFI to create Figure 2 and Figure 3 which depict the solvent plume in both the shallow and deeper portions of the surficial aquifer.

2.0 PROBLEM FORMULATION

Groundwater sampling performed upgradient of SWMU 163 and SWMU 166 has identified additional chlorinated solvent contamination (TCE primarily) in the deeper portion of the surficial aquifer which appears to be **unrelated** to the two known, on-site source areas.

Navy Hypothesis: The dissolved phase plume detected at locations GDKGP011 and GDKGP013 is emanating from a non-layered source zone (no low K units to cause Dense Non-Aqueous Phase Liquids (DNAPL) to perch) upgradient of the Naval Annex where a sufficient volume of DNAPL was released to fully penetrate the surficial aquifer. The conceptual model for the site is represented by "Scenario A" on the page following Figure 3.

The hypothesis was developed based on what is currently known about the hydrogeologic characteristics of the surficial aquifer, the spatial distribution of the dissolved phase plume, and a review of literature pertaining to the behavior of DNAPLs in groundwater. The basis for the hypothesis is explained below. Several terms used in the hypothesis are defined below so they are understood in the context in which they are used.

Source Zone — the portion of the site affected by free phase or residual DNAPL in the subsurface.

FIGURE 2

N

K-Area Property Boundary

CHLORINATED VOC's (in µg/L)
SHALLOW WELL LOCATION

- ND (Non-Detect)
- 1 - 10
- 10 - 100
- 100 - 1000
- 1000 - 10000
- 10000 - 20000

GROUNDWATER ELEVATION CONTOURS

- FEET (MSL)

SHALLOW PLUME SURFACE MODEL

- Greater Than 1000
- 100-1000
- 10-100
- 1-10

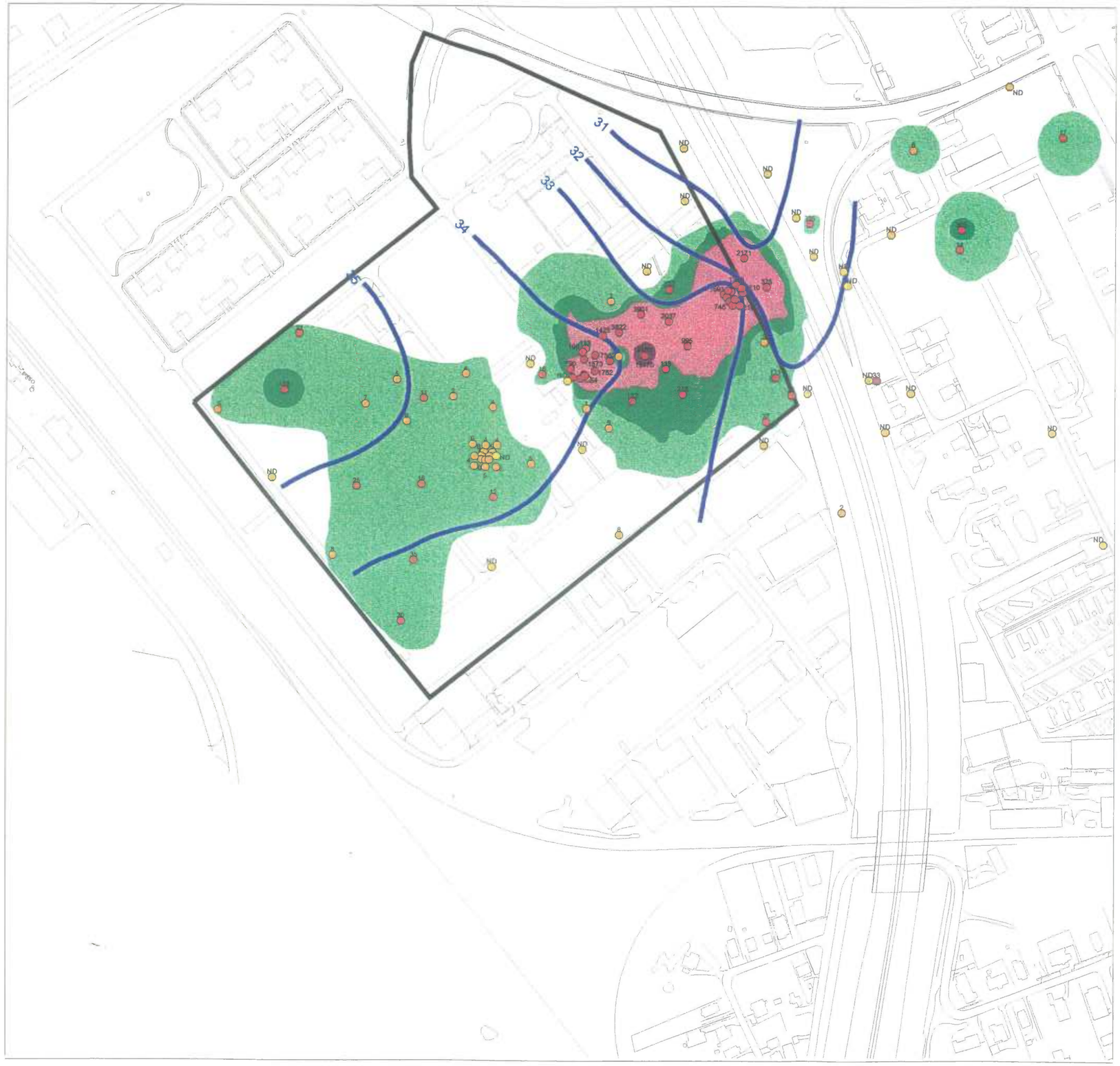
SCALE

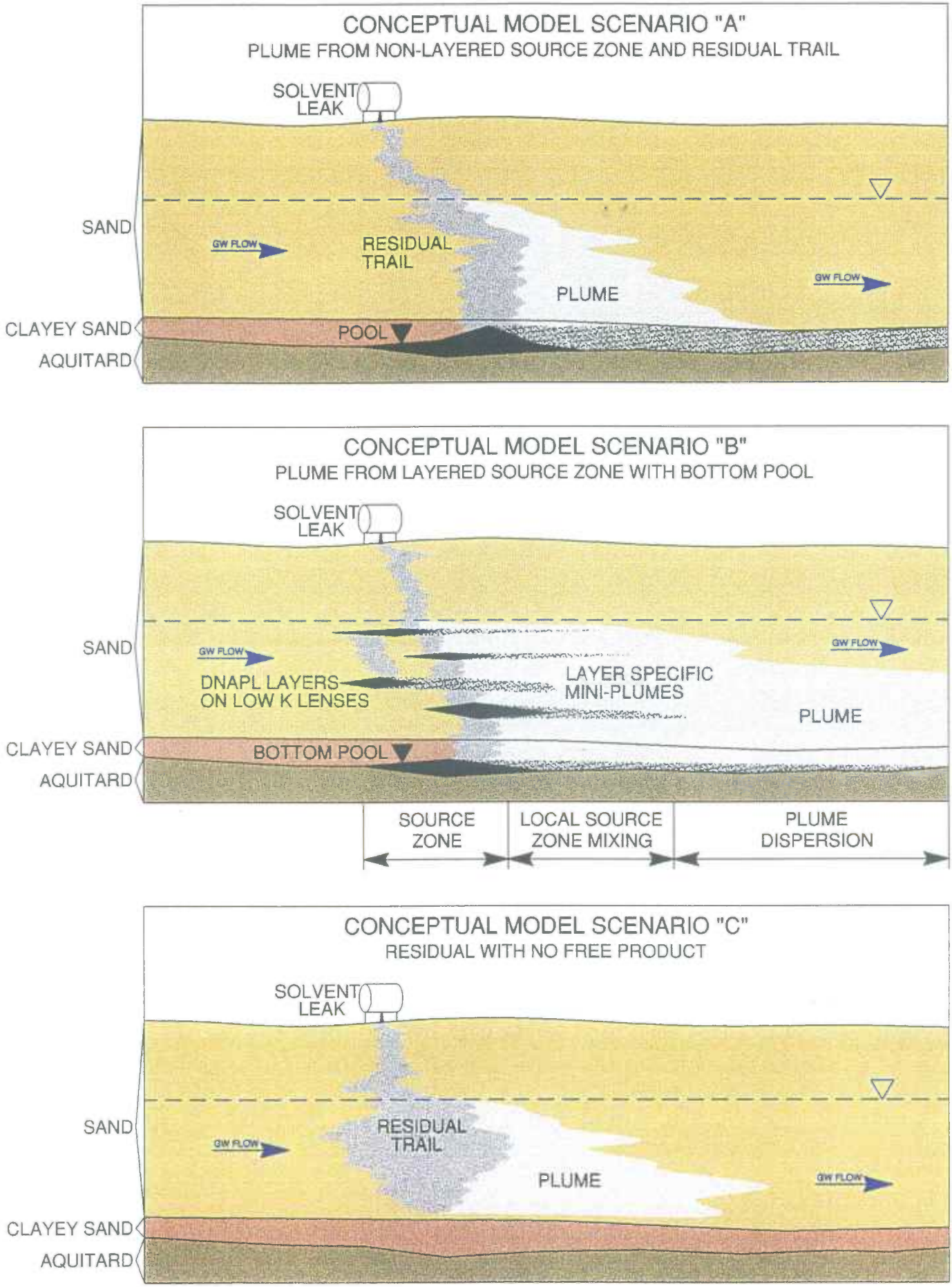
Miles
0 0.05 0.1

Feet
0 500

Kilometers
0 0.125

FIGURE 3


31
32
33
34
35
ND
2121
2037
3851
3822
985
745
1425
1575
782
264
139
335
10
N
K-Area Property Boundary
CHLORINATED VOC's (in µg/L)
DEEP WELL LOCATION
ND (Non-Detect)
1 - 10
10 - 100
100 - 1000
1000 - 10000
10000 - 20000
GROUNDWATER ELEVATION CONTOURS
FEET (MSL)
DEEP PLUME SURFACE MODEL
Greater Than 10000
1000-10000
100-1000
1-100
SCALE
Miles
0
0.05
Feet
0
500
Kilometers
0
0.125



ADAPTED FROM PANKOW AND CHERRY, 1996

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Plume — the zone of contamination containing inorganics in the dissolved phase.

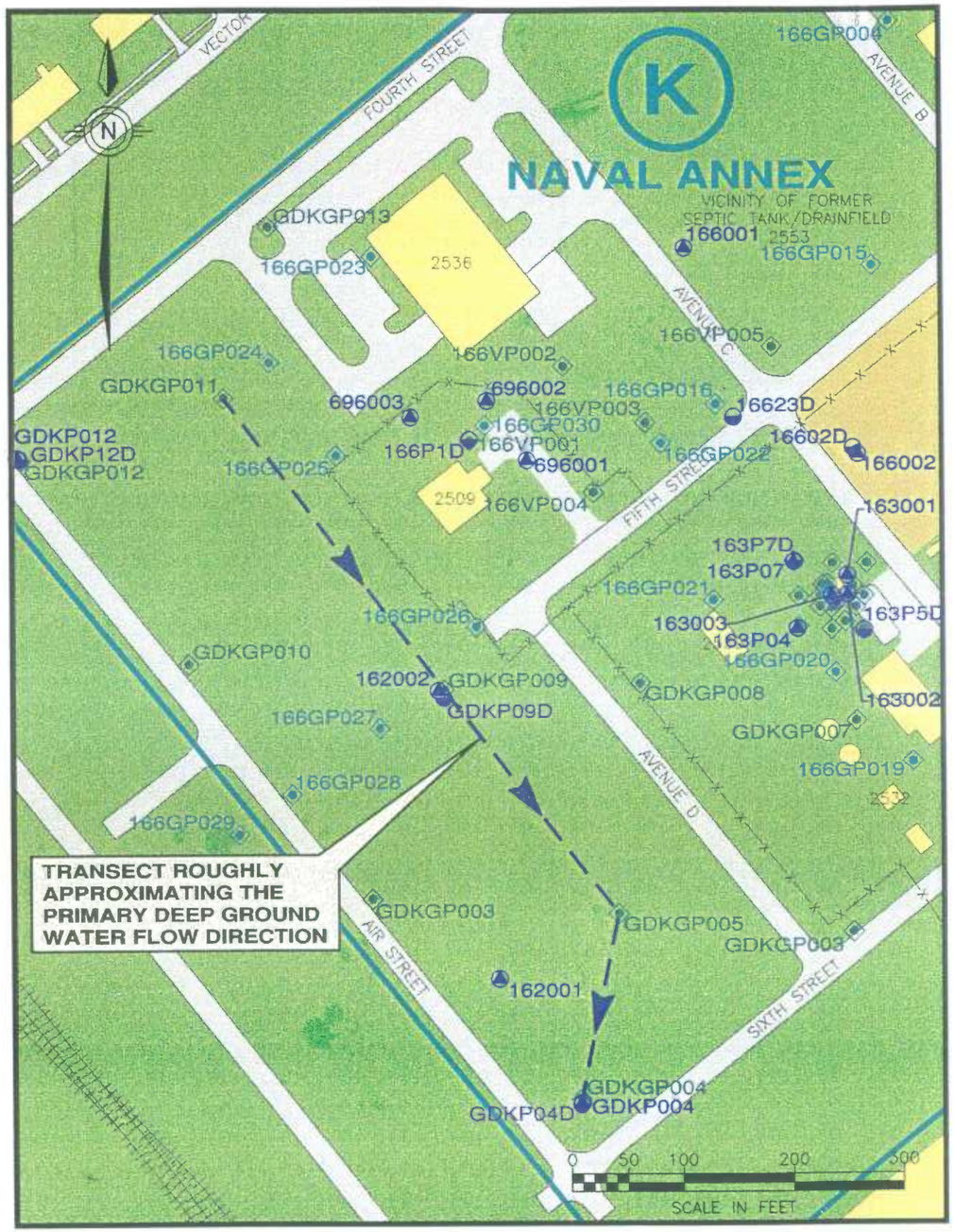
Residual DNAPL — DNAPL held in pore spaces by capillary forces.

DNAPL Pool — a zone of free phase DNAPL at the bottom of the aquifer.

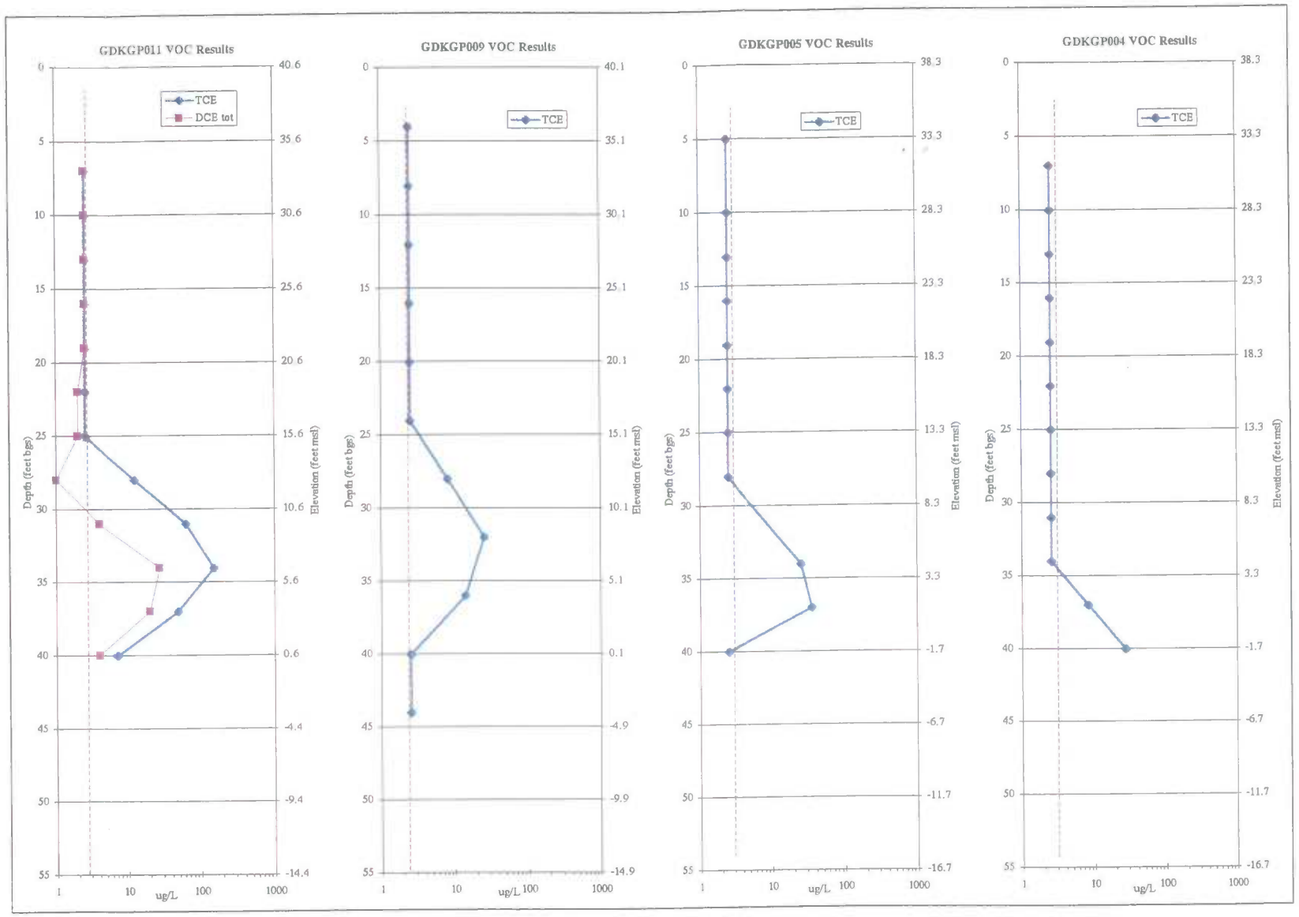
- **The source zone is "non-layered"**. The vertical profile data at GDKGP011 and GDKGP013 supports the geologic conceptual model that no low permeability (K) units such as clay stringers or lenses that have been identified impede the vertical migration of DNAPL from the water table surface and a clayey sand that overlies the Ashley Formation. No detections of chlorinated solvents occurred until the clayey sand was encountered. If additional low K units were present the result would have been a dissolved phase plume that exhibited some stratification based on DNAPL pooling or lenses at various depth intervals which is represented by "Scenario B" on the preceding page. The following is a brief synopsis of the subsurface geology description provided in Section 2 of the *Draft Zone K RFI Report* (EnSafe, 1998). The unconfined surficial aquifer extends from the water table to the top of the Ashley Formation, the regional confining unit. Overlying the Ashley is a clayey sand unit that consists of a fine to coarse, clayey sand with varying amounts of silt. Phosphate nodules from pebble to cobble size and shell hash are often intermixed within the matrix or as distinct basal lenses. Clay lenses, when present, are often green, firm to stiff, and plastic. The deep wells installed at Naval Annex are primarily screened within this unit. Overlying the clayey sand unit and extending to ground surface is a fine to medium sand with varying silt content and very distinctive mica content. The unit is marked by a lack of cohesiveness from limited fines content. Shallow wells installed at the Naval Annex are screened within this unit.

- **The volume of DNAPL released was sufficient to fully penetrate the surficial aquifer.** Transects of the dissolved phase plume both parallel and roughly transverse to the groundwater flow direction are presented in Figures 4 and 5. Both vertical profile transects show that a plume exists at a depth equivalent to the clayey sand unit overlying the Ashley Formation. From this information it can be inferred that the volume of DNAPL released was sufficient to penetrate to the bottom of the surficial aquifer where a thin dissolved phase plume has been created by the dissolution of the DNAPL source material that has accumulated on/within lower permeability material. If the DNAPL source was depleted prior to the DNAPL fully penetrating the aquifer, it would have resulted in a plume similar to that presented in "Scenario C". Plume concentrations in the vicinity of GDKGP011 may be large relative to drinking water standards but they are not large enough to cause the plume to sink due to the density of the aqueous solution. Density is an important factor at DNAPL sites, but only with respect to vertical movement of the DNAPL (Pankow and Cherry, 1996). Across the western portion of the Naval Annex, which is nearest to the study area defined below, the vertical hydraulic gradient that was measured is so slight that for all practical purpose groundwater flow is consider horizontal. As a result it is unlikely the vertical gradient has had any significant impact on the movement of the dissolved phase plume. Attachment B contains information extracted from the *Draft Zone K RFI Report* (EnSafe, 1998) that pertains to the horizontal and vertical components of groundwater flow.

- **The source zone is upgradient of the northwest boundary of the Naval Annex.** As mentioned above, movement of the dissolved phase plume is controlled largely by dispersion along the primary groundwater flow paths. Groundwater flow paths are diverging in the vicinity of GDKGP011 due to localized influences caused by the construction of I-26 and Filbin Creek, but groundwater flow direction in the vicinity of GDKGP011 is generally from west to east. The chemical data suggests that the component



DEEP GROUNDWATER VOCs ALONG TRANSECT PARALLEL TO DEEP GROUNDWATER FLOW (LEFT TO RIGHT)



Red dashes represent 1/2 detection limit (2.5 ug/L).

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FIGURE 4
VERTICAL PROFILE DATA
TRANSECT MAP

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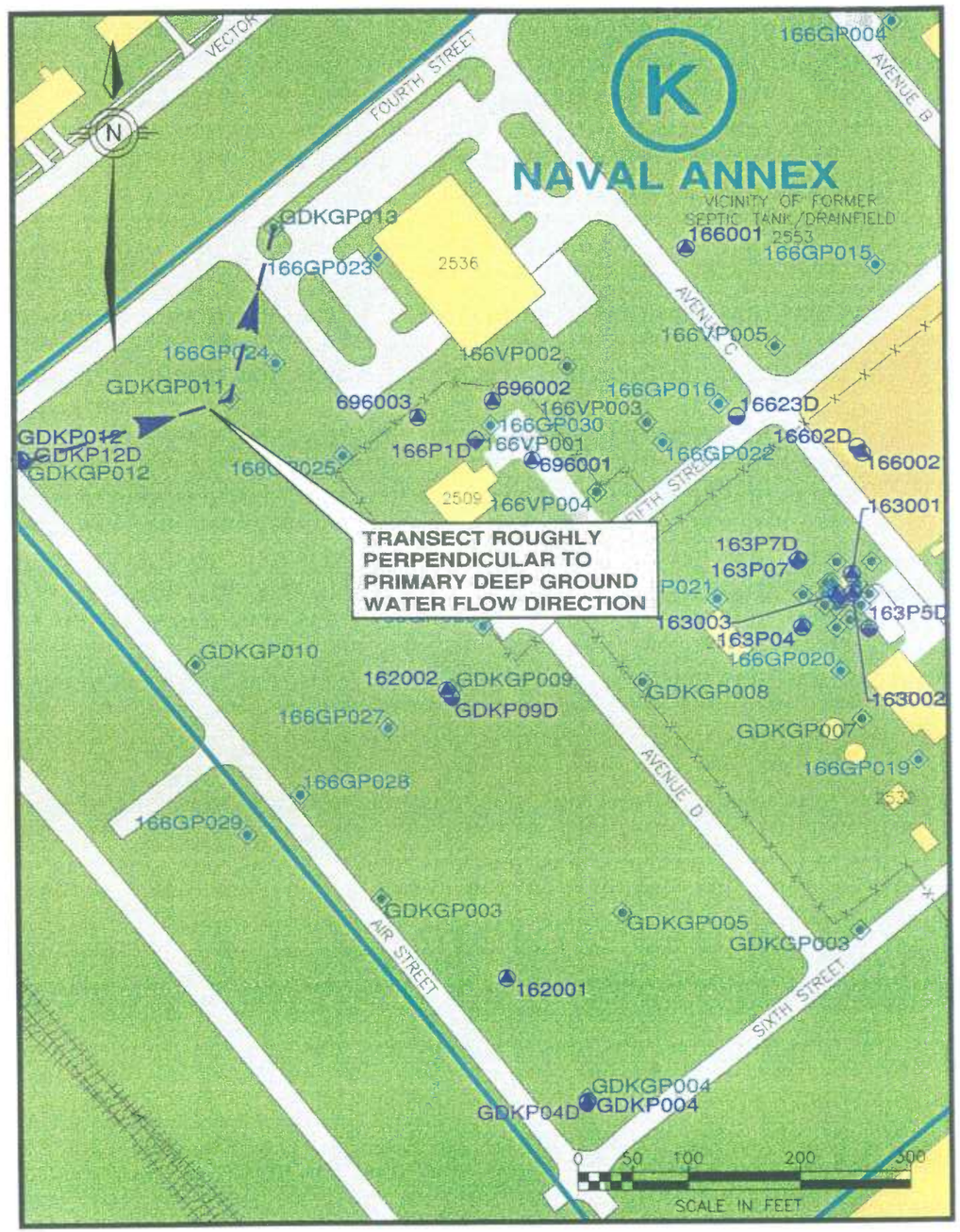
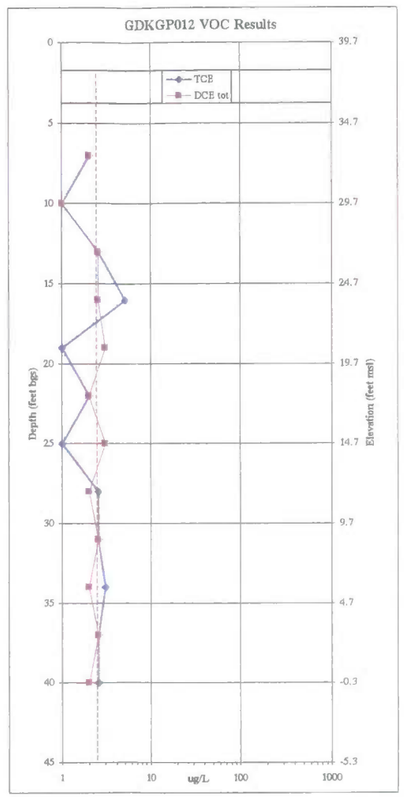
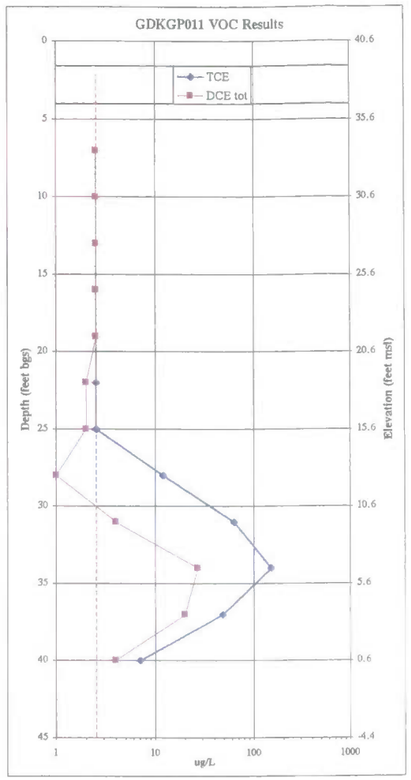
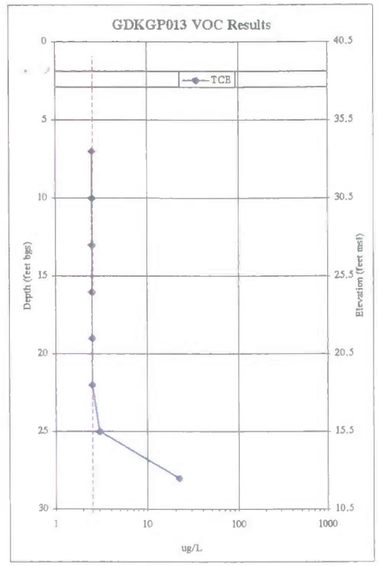
DEEP GROUNDWATER VOCs ALONG TRANSECT PERPENDICULAR TO DEEP GROUNDWATER FLOW (LEFT TO RIGHT)









Red dashes represent 1/2 detection limit (2.5 ug/L)

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FIGURE 5
VERTICAL PROFILE DATA
TRANSECT MAP

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of groundwater flow diverging in a southeasterly direction is having a greater influence on plume migration as shown by the higher concentrations in that direction. Attempting to estimate how far upgradient the source area may be would be speculative at best because of all of the variables that can affect DNAPL movement. However, in developing a conceptual model for the release and formation of the plume it was assumed that close to the source area the dissolved phase plume should span the entire depth of the aquifer at some locations since studies have indicated that DNAPL residual that will remain trapped in 1% to 25% of the pore space within the aquifer matrix (Mercer and Cohen, 1990). Residual zones may be relatively small and disconnected from one another. As a consequence, with increasing distance from the source, the initially saturated concentrations from the residual zones may become diluted significantly (Pankow and Cherry, 1996). The absence of the dissolved phase plume at depths shallower than 25 ft bgs at locations GDKGP011 and GDKGP013 suggests that the source may by some distance upgradient of these locations since the only contamination seen is from the portion of the plume emanating from the DNAPL pool which has penetrated to the bottom of the aquifer.

3.0 DECISION NEEDING TO BE MADE

The fundamental question to be answered: Did the contamination detected at sample point GDKGP011 originate from a source on the Navy property, is it a result of contamination migrating onto the Navy property from an offsite source, or is it the result of co-mingled contamination from a source(s) on Navy property as well as an off-site source(s)?

4.0 INFORMATION NEEDED TO MAKE THE DECISION

Additional data is needed from locations off-site and upgradient of GDKGP011 to supplement the Naval Annex data to help determine if contamination from an off-site source is migrating on to Navy property. These data consist of:

- Groundwater analytical data (volatile organic compounds only).
- Continuous soil cores to the top of the Ashley Formation (Ta) for stratigraphic control.
- Potentiometric surface data for the shallow and deep portions of the surficial aquifer.

The data should be sufficient to produce 1 of the 2 following outcomes:

- In the absence of any solvent (PCE, TCE, dichloroethene (DCE)) compounds at the proposed off-site locations, it will be presumed that the source area is on Naval Annex property. The Navy, CH2M Hill, and South Carolina Department of Health and Environmental Control (SCDHEC) will meet to reach consensus agreement on an interpretation of the data and develop a path forward.

- If off-site detections occur, the Air Force, Navy, and SCDHEC will meet to reach consensus agreement on an interpretation of the data and develop a path forward.

The Navy will coordinate with the Air Force to provide a two week notification prior to field work to allow the Air Force to arrange for technical oversight.

5.0 OFF-SITE STUDY AREA BOUNDARY

There may be other issues remaining with respect to groundwater contamination in Zone K but, for purposes of answering the question posed above, the study area should be confined to the area described below.

- Vertical boundaries: All solvent contamination is limited to the surficial aquifer, which overlies the regional confining unit, the Ashley Formation. The Ta surface has been contoured throughout the Annex to determine the bottom of the surficial aquifer.

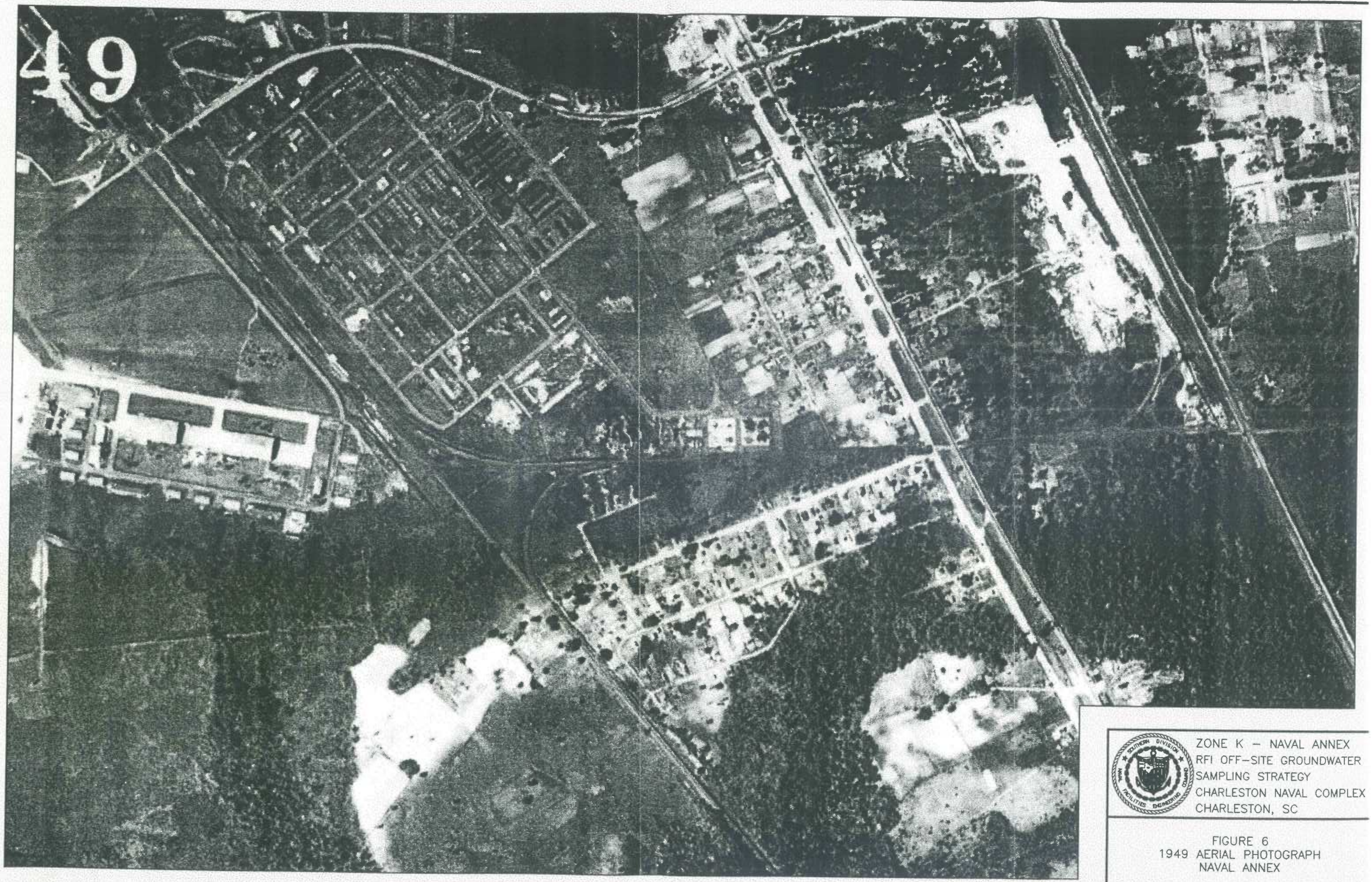

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FIGURE 6
1949 AERIAL PHOTOGRAPH
NAVAL ANNEX

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The proposed activities in the order in which they will be performed are as follows:

- Two lithologic borings will be drilled to obtain continuous soil cores from the ground surface to the top of the Ashley formation at proposed locations OFFGP003 and OFFGP006. This information will be correlated to the existing lithostratigraphic data generated during previous phases of the RFI to select the optimum sampling depths.

- Two shallow/deep piezometer pairs will be installed at proposed locations OFFGP003 and OFFGP006 to provide additional control with respect to determining groundwater flow direction upgradient of the Naval Annex. Water level measurements will be obtained from the new piezometers along with a sufficient number of piezometers/wells on the Naval Annex property to construct a new potentiometric surface diagram to determine if any of the locations proposed below need to be adjusted.

- Groundwater samples are proposed to be collected from 10 off-site locations using vertical profiling and direct push technology (DPT). The proposed locations are shown on the attached aerial photo figure. Sampling will start with the locations closest to the Naval Annex property and proceed outward towards the two locations proposed in the department of transportation (DOT) right-of-way along Remount Road. Groundwater samples will be collected from approximately eight depth intervals. The sampling will begin just below the water table (approximately 10 feet below ground surface) and every 5 feet thereafter with the target being the clayey sand overlying the Ashley Formation. The total depth of each boring is anticipated to be approximately 45 feet. The interval depth near the clayey sand is believed to be of most significance to meet the goal of the sampling plan due to the following conditions which create a reasonable margin for error.

— The dissolved phase plume is distributed over a vertical interval of 15 feet.

— The highest concentrations will be a depth as shown by the vertical profiles already completed. If a non-detect occurs, the sample was either collected upgradient of the source zone or the plume was missed laterally.

— The potential for missing the plume laterally would be a concern if groundwater flow was uniform since chlorinated solvents under those conditions have a tendency to form long, narrow plumes because transverse dispersion is weak relative to longitudinal dispersion. However, near GDKGP011 groundwater flow paths are divergent which means the plume will be more fan shaped in nature since both transverse and longitudinal dispersion will be occurring. This is probably at least one of the causes of the widespread, low level detections seen across the western portion of the Naval Annex.

— The likelyhood of missing the plume is further reduced by the quantity and location of the sampling points proposed.

Analysis of the samples (VOCs only) will be performed in the field using a mobile lab.

7.0 IDW MANAGEMENT

The Navy will be responsible for the containerization, profiling, and generation of the manifest of any industrial derived waste(IDW) generated off-site. The manifest for IDW generated on Air Force property will be provided to the Air Force for signature while a separate manifest for IDW generated outside the boundary of the Air Force property will be signed by the Navy. Figure 7 shows the boundary of the Air Force property and which of the proposed sample

locations are within that boundary. Specific details on the management of IDW can be found in the 1996 Comprehensive Sampling and Analysis Plan for CNC.

8.0 SCHEDULE AND REPORTING

Appendix B contains a schedule for implementation of the groundwater sampling strategy. The schedule simply shows durations in calendar days for individual tasks since the actual start date is not known at this time. Upon completion of the field activities, a brief technical memorandum summarizing the outcome of the sampling efforts will be prepared. The memo will contain a description of the sampling activities, a map depicting the surveyed locations of the sampling points, potentiometric surface contour maps for both the shallow and deep flow zones of the surficial aquifer, a tabular and graphical presentation of the data, and an interpretation of the data. The report will be submitted to SCDHEC, USEPA and the Air Force.

9.0 REFERENCES

EnSafe Inc. (1996). *Final Comprehensive Sampling and Analysis Plan*, EnSafe Inc.: Memphis, Tennessee.

EnSafe Inc. (1998). *Draft Zone K RFI Report*, EnSafe Inc.: Memphis, Tennessee.

Mercer, J.W. and R.M. Cohen. 1990. *A review of immiscible fluids in the subsurface: Properties, models, characterization and remediation*. J. of Contaminant Hydrology. V. 6, pp.107-163.

Pankow, J.F., J.A. Cherry. 1996. *Dense Chlorinated Solvents and other DNAPLs in Groundwater*. Waterloo Press. 522 p.

10.0 SIGNATORY REQUIREMENT

Condition I.E. of the Hazardous and Solid Waste Amendments (HSWA) portion of RCRA Part B Permit (EPA SCO 170 022 560) states: *All applications, reports, or information submitted to the Regional Administrator shall be signed and certified in accordance with 40 CFR §270.11.* The certification reads as follows:

I certify under penalty of law that this document and all attachments were prepared under by direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Matthew A. Hunt

Matthew A. Hunt
BRAC Environmental Coordiator

9/5/00

Date

SWMU 166 and GDK Ve[illegible]l Profile VOC Results
Zone K Annex-Charleston Naval Complex

GDK VERTICAL PROFILE VOC RESULTS										
ID	**depth ft bgs**	**elev**	**PCE**	**TCE**	**cis DCE**	**DCE tot**	**B**	**T**	**E**	**X**
NG elev		39.5								
GDKGP00207	7	32.5	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00210	10	29.5	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00213	13	26.5	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00216	16	23.5	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00219	19	20.5	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00222	22	17.5	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00225	25	14.5	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00228	28	11.5	ND	4	4	4	ND	ND	ND	ND
NG elev		38.8								
GDKGP00310	10	28.8	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00313	13	25.8	ND	ND	44	44	ND	ND	ND	ND
GDKGP00316	16	22.8	ND	ND	38	38	ND	ND	6	ND
GDKGP00319	19	19.8	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00322	22	16.8	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00325	25	13.8	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00331	31	7.8	ND	ND	ND	ND	ND	ND	ND	ND
NG elev		38.3								
GDKGP00407	7	31.3	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00410	10	28.3	ND	ND	ND	1	ND	ND	ND	ND
GDKGP00413	13	25.3	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00416	16	22.3	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00419	19	19.3	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00422	22	16.3	ND	ND	1	3	ND	ND	ND	ND
GDKGP00425	25	13.3	ND	ND	ND	2	ND	ND	ND	ND
GDKGP00428	28	10.3	ND	ND	1	1	ND	ND	ND	ND
GDKGP00431	31	7.3	ND	ND	ND	2	ND	ND	ND	ND
GDKGP00434	34	4.3	ND	ND	ND	1	ND	ND	ND	ND
GDKGP00437	37	1.3	ND	8	ND	2	ND	ND	ND	ND
GDKGP00440	40	-1.7	1	27	ND	2	1	ND	ND	ND

ND = Not Detected at 5 *u* g/L Detection Level

SWMU 166 and GDK Ve[illegible] Profile VOC Results
Zone K Annex-Charleston Naval Complex

ID	depth ft bgs	elev	PCE	TCE	cis DCE	DCE tot	B	T	E	X
NG elev		38.3								
GDKGP00507	5	33.3	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00510	10	28.3	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00513	13	25.3	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00516	16	22.3	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00519	19	19.3	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00522	22	16.3	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00525	25	13.3	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00528	28	10.3	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00534	34	4.3	ND	25	ND	ND	ND	ND	ND	ND
GDKGP00537	37	1.3	ND	35	ND	ND	ND	ND	ND	ND
GDKGP00540	40	-1.7	ND	ND	ND	ND	ND	ND	ND	ND
NG elev		38.2								
GDKGP00607	7	31.2	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00610	10	28.2	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00613	13	25.2	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00616	16	22.2	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00619	19	19.2	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00622	22	16.2	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00625	25	13.2	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00628	28	10.2	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00631	31	7.2	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00634	34	4.2	ND	7	ND	ND	ND	ND	ND	ND
GDKGP00637	37	1.2	ND	ND	1	1	ND	ND	ND	ND
GDKGP00640	40	-1.8	ND	ND	ND	ND	ND	ND	ND	ND
NG elev		39.6								
GDKGP00707	7	32.6	2	2	2	4	ND	ND	ND	ND
GDKGP00710	10	29.6	1	2	ND	2	ND	ND	ND	ND
GDKGP00713	13	26.6	4	4	3	6	ND	ND	ND	ND
GDKGP00716	16	23.6	ND	ND	ND	2	ND	ND	ND	ND
GDKGP00719	19	20.6	1	2	2	5	ND	ND	ND	ND
GDKGP00722	22	17.6	ND	4	ND	2	ND	ND	ND	ND
GDKGP00725	25	14.6	2	5	2	2	ND	ND	ND	ND
GDKGP00728	28	11.6	ND	5	2	7	ND	ND	ND	ND

ND = Not Detected at 5 *u* g/L Detection Level

SWMU 166 and GDK Ve[illegible] Profile VOC Results
Zone K Annex-Charleston Naval Complex

ID	depth ft bgs	elev	PCE	TCE	cis DCE	DCE tot	B	T	E	X
NG elev		39.5								
GDKGP00807	7	32.5	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00810	10	29.5	1	3	1	4	ND	ND	ND	ND
GDKGP00813	13	26.5	1	2	2	4	3	ND	3	5
GDKGP00816	16	23.5	2	2	ND	3	ND	ND	ND	ND
GDKGP00819	19	20.5	2	1	1	4	ND	ND	ND	ND
GDKGP00822	22	17.5	1	3	2	5	ND	ND	ND	ND
GDKGP00825	25	14.5	2	3	ND	2	ND	ND	ND	ND
GDKGP00828	28	11.5	3	4	ND	3	ND	ND	ND	ND
GDKGP00834	34	5.5	2	10	1	4	ND	ND	ND	ND
GDKGP00837	37	2.5	2	2	ND	3	8	3	2	2
NG elev		40.1								
GDKGP00904	4	36.1	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00908	8	32.1	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00912	12	28.1	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00916	16	24.1	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00920	20	20.1	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00924	24	16.1	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00928	28	12.1	ND	8	ND	ND	ND	ND	ND	ND
GDKGP00932	32	8.1	ND	25	ND	ND	ND	ND	ND	ND
GDKGP00936	36	4.1	ND	14	2	2	3	ND	ND	ND
GDKGP00940	40	0.1	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP00944	44	-3.9	ND	ND	ND	ND	ND	ND	ND	ND
NG elev		39.1								
GDKGP01007	7	32.1	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01010	10	29.1	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01013	13	26.1	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01016	16	23.1	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01019	19	20.1	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01022	22	17.1	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01025	25	14.1	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01028	28	11.1	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01031	31	8.1	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01034	34	5.1	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01037	37	2.1	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01040	40	-0.9	ND	ND	ND	ND	ND	ND	ND	ND

ND = Not Detected at 5 *u* g/L Detection Level

SWMU 166 and GDK Ve[illegible]. Profile VOC Results
Zone K Annex-Charleston Naval Complex

ID	depth ft bgs	elev	PCE	TCE	cis DCE	DCE tot	B	T	E	X
NG elev		40.6								
GDKGP01107	7	33.6	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01110	10	30.6	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01113	13	27.6	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01116	16	24.6	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01119	19	21.6	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01122	22	18.6	ND	ND	ND	2	ND	ND	ND	ND
GDKGP01125	25	15.6	ND	ND	ND	2	ND	ND	ND	ND
GDKGP01128	28	12.6	2	12	1	1	ND	ND	ND	ND
GDKGP01131	31	9.6	2	62	2	4	ND	ND	ND	ND
GDKGP01134	34	6.6	1	150	22	27	8	ND	ND	ND
GDKGP01137	37	3.6	1	48	18	20	4	ND	ND	ND
GDKGP01140	40	0.6	1	7	2	4	ND	ND	ND	ND
NG elev		39.7								
GDKGP01207	7	32.7	1	2	ND	2	ND	ND	ND	ND
GDKGP01210	10	29.7	1	1	ND	1	ND	ND	ND	ND
GDKGP01213	13	26.7	1	ND	ND	ND	ND	ND	ND	ND
GDKGP01216	16	23.7	ND	5	ND	ND	ND	ND	ND	ND
GDKGP01219	19	20.7	ND	1	2	3	ND	ND	ND	ND
GDKGP01222	22	17.7	1	2	ND	2	ND	ND	ND	ND
GDKGP01225	25	14.7	2	1	1	3	ND	ND	ND	ND
GDKGP01228	28	11.7	1	ND	ND	2	ND	ND	ND	ND
GDKGP01231	31	8.7	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01234	34	5.7	ND	3	ND	2	ND	ND	ND	ND
GDKGP01237	37	2.7	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01240	40	-0.3	ND	ND	ND	2	ND	ND	ND	ND
NG elev		40.5								
GDKGP01307	7	33.5	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01310	10	30.5	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01313	13	27.5	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01316	16	24.5	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01319	19	21.5	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01322	22	18.5	ND	ND	ND	ND	ND	ND	ND	ND
GDKGP01325	25	15.5	ND	3	ND	ND	ND	ND	ND	ND
GDKGP01328	28	12.5	ND	22	ND	ND	ND	ND	ND	ND

ND = Not Detected at 5 *u* g/L Detection Level

SWMU 166 and GDK V[illegible], Profile VOC Results
Zone K Annex-Charleston Naval Complex

ID	depth ft bgs	elev	PCE	TCE	cis DCE	DCE tot	B	T	E	X
166 VERTICAL PROFILE VOC RESULTS										
NG elev		41.2								
166VP00105	5	36.2	ND	ND	ND	ND	ND	ND	ND	ND
166VP00108	8	33.2	ND	ND	ND	ND	ND	ND	ND	ND
166VP00111	11	30.2	ND	ND	ND	ND	ND	ND	ND	ND
166VP00114	14	27.2	ND	ND	ND	ND	ND	ND	ND	ND
166VP00117	17	24.2	ND	ND	ND	ND	ND	ND	ND	ND
166VP00120	20	21.2	ND	ND	ND	ND	ND	ND	ND	ND
166VP00123	23	18.2	ND	ND	ND	ND	ND	ND	ND	ND
166VP00126	26	15.2	ND	ND	ND	ND	ND	ND	ND	ND
166VP00129	29	12.2	ND	7.3	ND	ND	ND	ND	ND	ND
166VP00132	32	9.2	ND	ND	ND	ND	ND	ND	ND	ND
NG elev		40.5								
166VP00205	5	35.5	ND	ND	ND	ND	ND	ND	ND	ND
166VP00208	8	32.5	ND	ND	ND	ND	ND	ND	ND	ND
166VP00211	11	29.5	ND	ND	ND	ND	ND	ND	ND	ND
166VP00214	14	26.5	ND	ND	ND	ND	ND	ND	ND	ND
166VP00217	17	23.5	ND	ND	ND	ND	ND	ND	ND	ND
166VP00220	20	20.5	ND	ND	ND	ND	ND	ND	ND	ND
166VP00223	23	17.5	ND	1	ND	ND	ND	ND	ND	ND
166VP00226	26	14.5	ND	5.2	ND	ND	ND	ND	ND	ND
166VP00230	30	10.5	ND	ND	ND	ND	ND	ND	ND	ND
NG elev		39.9								
166VP00305	5	34.9	ND	ND	ND	ND	ND	ND	ND	ND
166VP00308	8	31.9	ND	ND	ND	ND	ND	ND	ND	ND
166VP00311	11	28.9	ND	ND	ND	ND	ND	ND	ND	ND
166VP00314	14	25.9	ND	ND	ND	ND	ND	ND	ND	ND
166VP00317	17	22.9	ND	ND	ND	ND	ND	ND	ND	ND
166VP00320	20	19.9	ND	ND	ND	ND	ND	ND	ND	ND
166VP00323	23	16.9	ND	ND	ND	ND	ND	ND	ND	ND
166VP00326	26	13.9	ND	9.2	ND	ND	ND	ND	ND	ND
166VP00329	29	10.9	ND	1.6	ND	ND	ND	ND	ND	ND

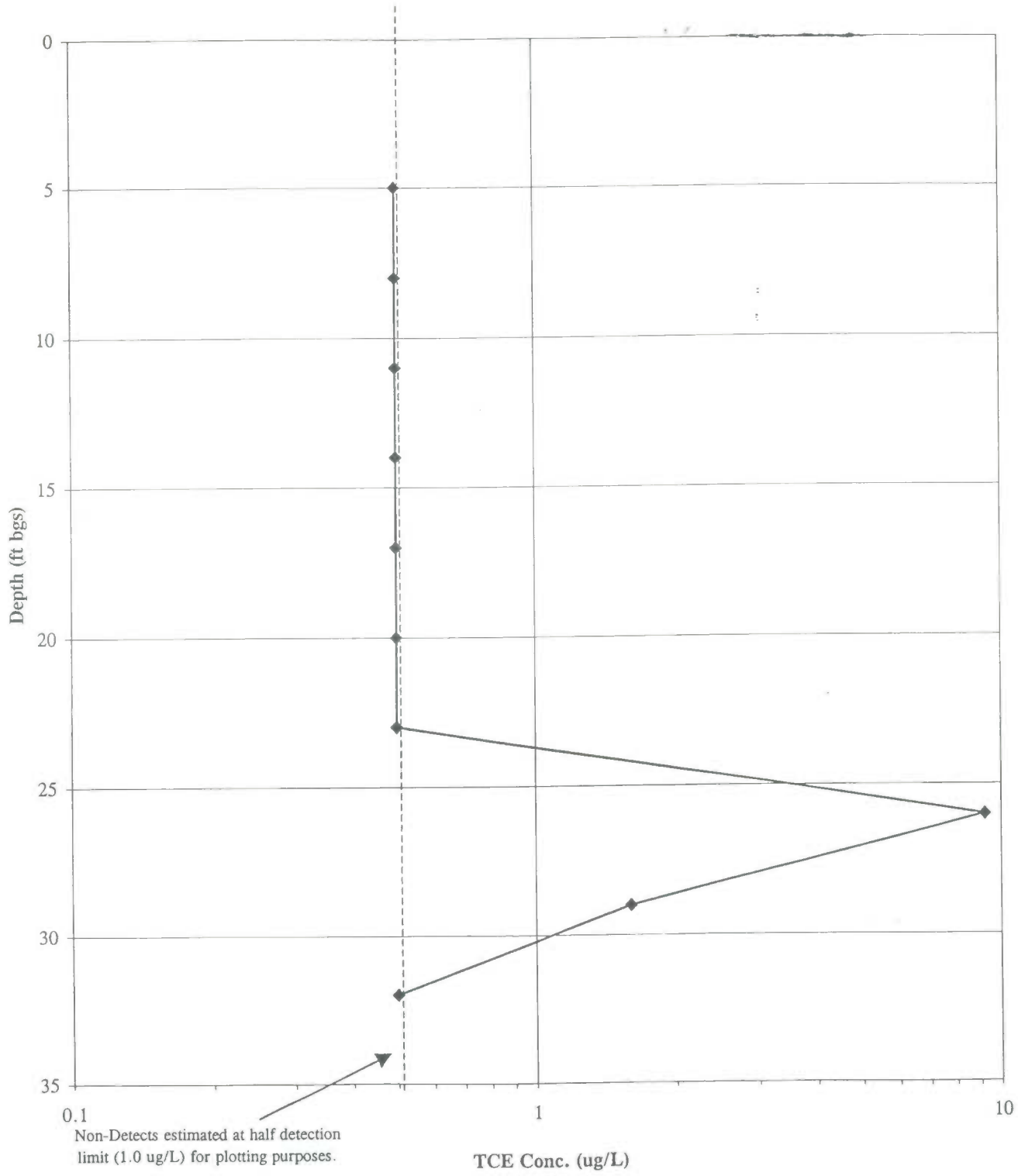
ND = Not Detected at 5 *u* g/L Detection Level

SWMU 166 and GDK Ve[illegible] Profile VOC Results
Zone K Annex-Charleston Naval Complex

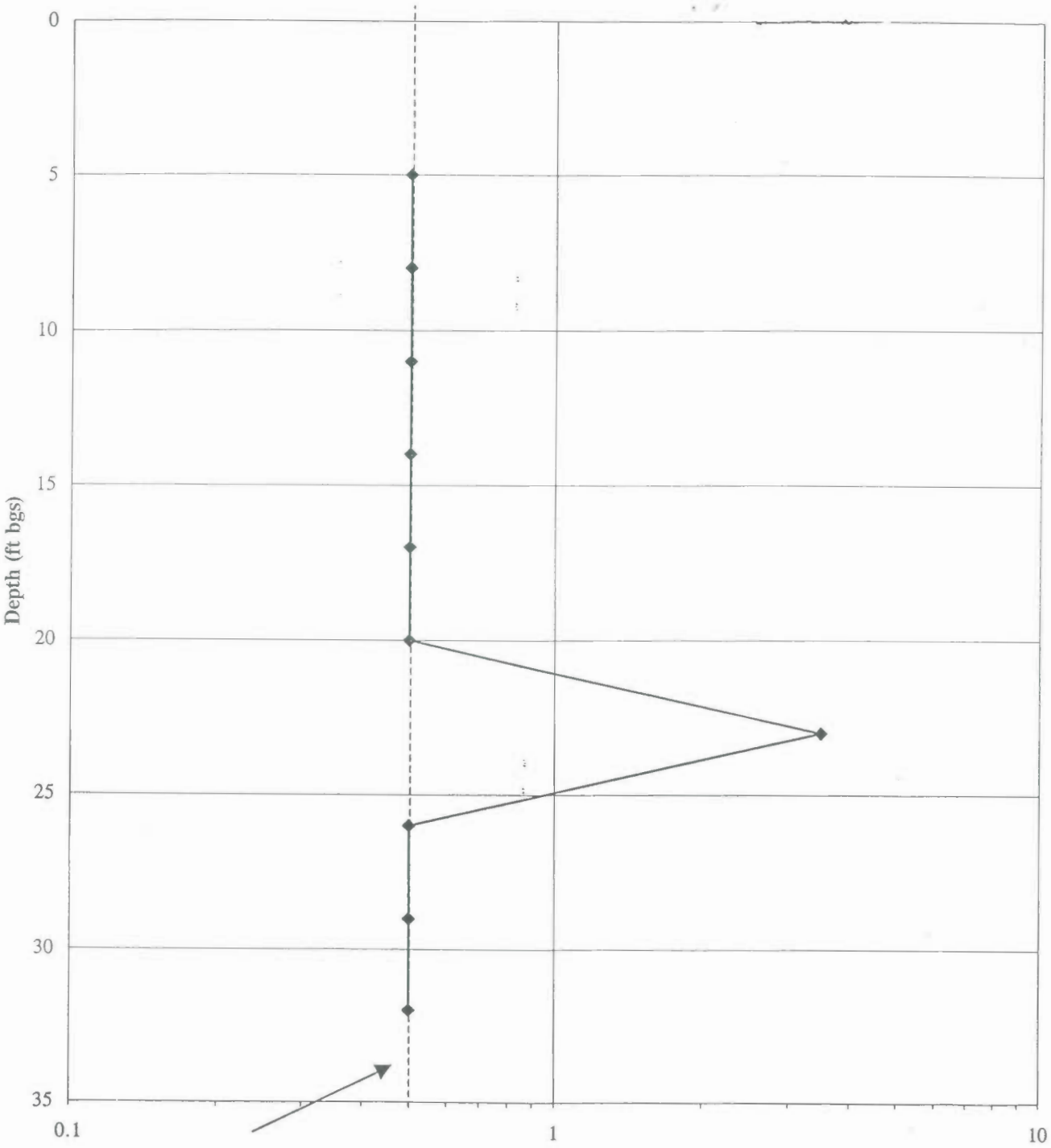
ID	depth ft bgs	elev	PCE	TCE	cis DCE	DCE tot	B	T	E	X
NG elev		39.8								
166VP00405	5	34.8	ND	ND	ND	ND	ND	ND	ND	ND
166VP00408	8	31.8	ND	ND	ND	ND	ND	ND	ND	ND
166VP00411	11	28.8	ND	ND	ND	ND	ND	ND	ND	ND
166VP00414	14	25.8	ND	ND	ND	ND	ND	ND	ND	ND
166VP00417	17	22.8	ND	ND	ND	ND	ND	ND	ND	ND
166VP00420	20	19.8	ND	ND	ND	ND	ND	ND	ND	ND
166VP00423	23	16.8	ND	ND	ND	ND	ND	ND	ND	ND
166VP00426	26	13.8	ND	7.6	ND	ND	ND	ND	ND	ND
166VP00429	29	10.8	ND	ND	ND	ND	ND	ND	ND	ND
166VP00432	32	7.8	ND	ND	ND	ND	ND	ND	ND	ND
NG elev		39.6								
166VP00505	5	34.6	ND	ND	ND	ND	ND	ND	ND	ND
166VP00508	8	31.6	ND	ND	ND	ND	ND	ND	ND	ND
166VP00511	11	28.6	ND	ND	ND	ND	ND	ND	ND	ND
166VP00514	14	25.6	ND	ND	ND	ND	ND	ND	ND	ND
166VP00517	17	22.6	ND	ND	ND	ND	ND	ND	ND	ND
166VP00520	20	19.6	ND	ND	ND	ND	ND	ND	ND	ND
166VP00523	23	16.6	ND	3.5	ND	ND	ND	ND	ND	ND
166VP00526	26	13.6	ND	ND	ND	ND	ND	ND	ND	ND
166VP00529	29	10.6	ND	ND	ND	ND	ND	ND	ND	ND
166VP00532	32	7.6	ND	ND	ND	ND	ND	ND	ND	ND
Notes:										
B	= Benzene									
cis DCE	= cis-1,2-Dichloroethene									
DCE tot	= 1,2-Dichloroethene total									
E	= Ethylbenzene									
NG elev	= Natural Ground Elevation									
PCE	= Tetrachloroethene									
TCE	= Trichloroethene									
T	= Toluene									
X	= Xylene									

ND = Not Detected at 5 *u* g/L Detection Level

166VP003

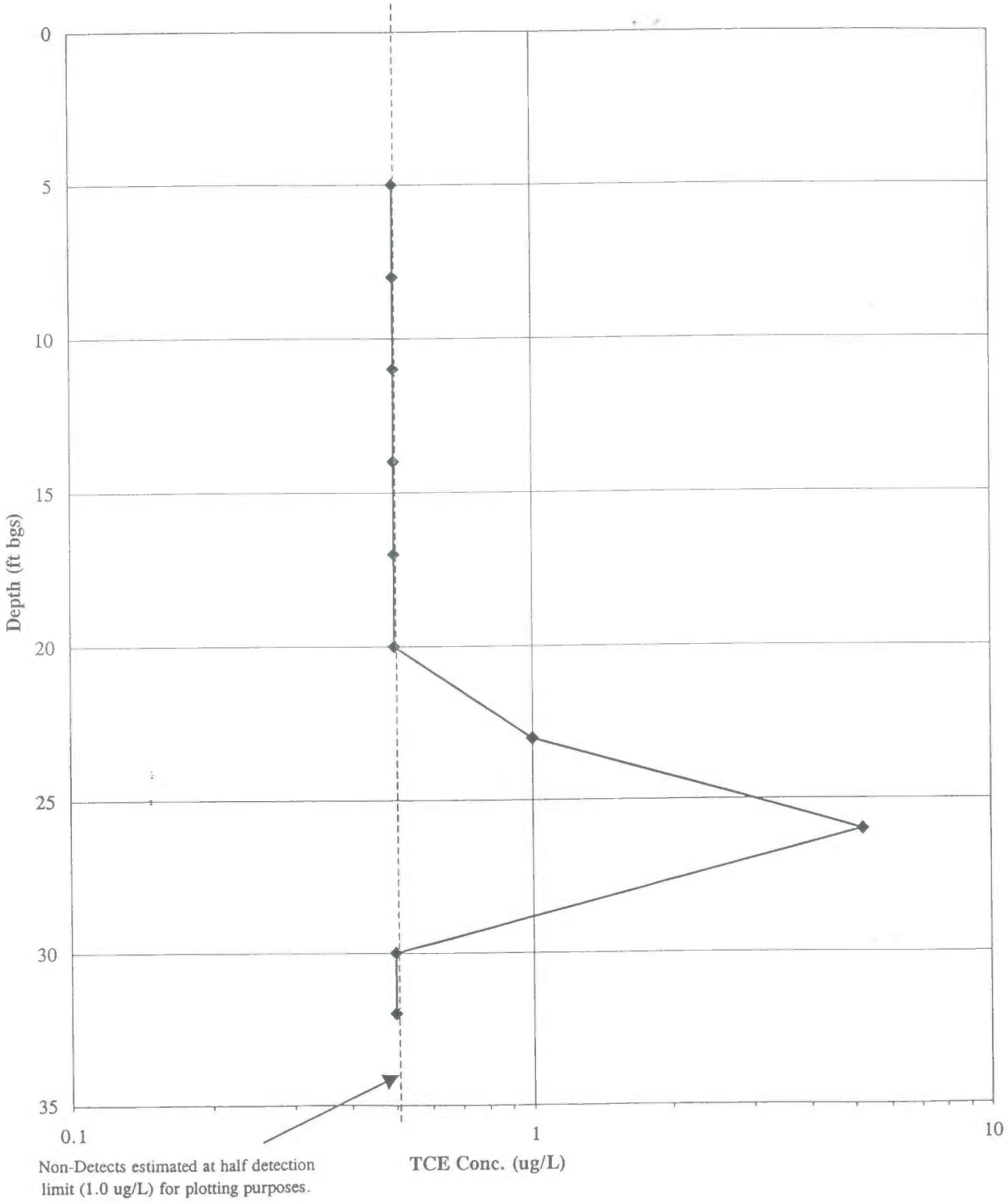

0
5
10
15
20
25
30
35
Depth (ft bgs)
0.1
1
10
Non-Detects estimated at half detection limit (1.0 ug/L) for plotting purposes.
TCE Conc. (ug/L)

166VP005

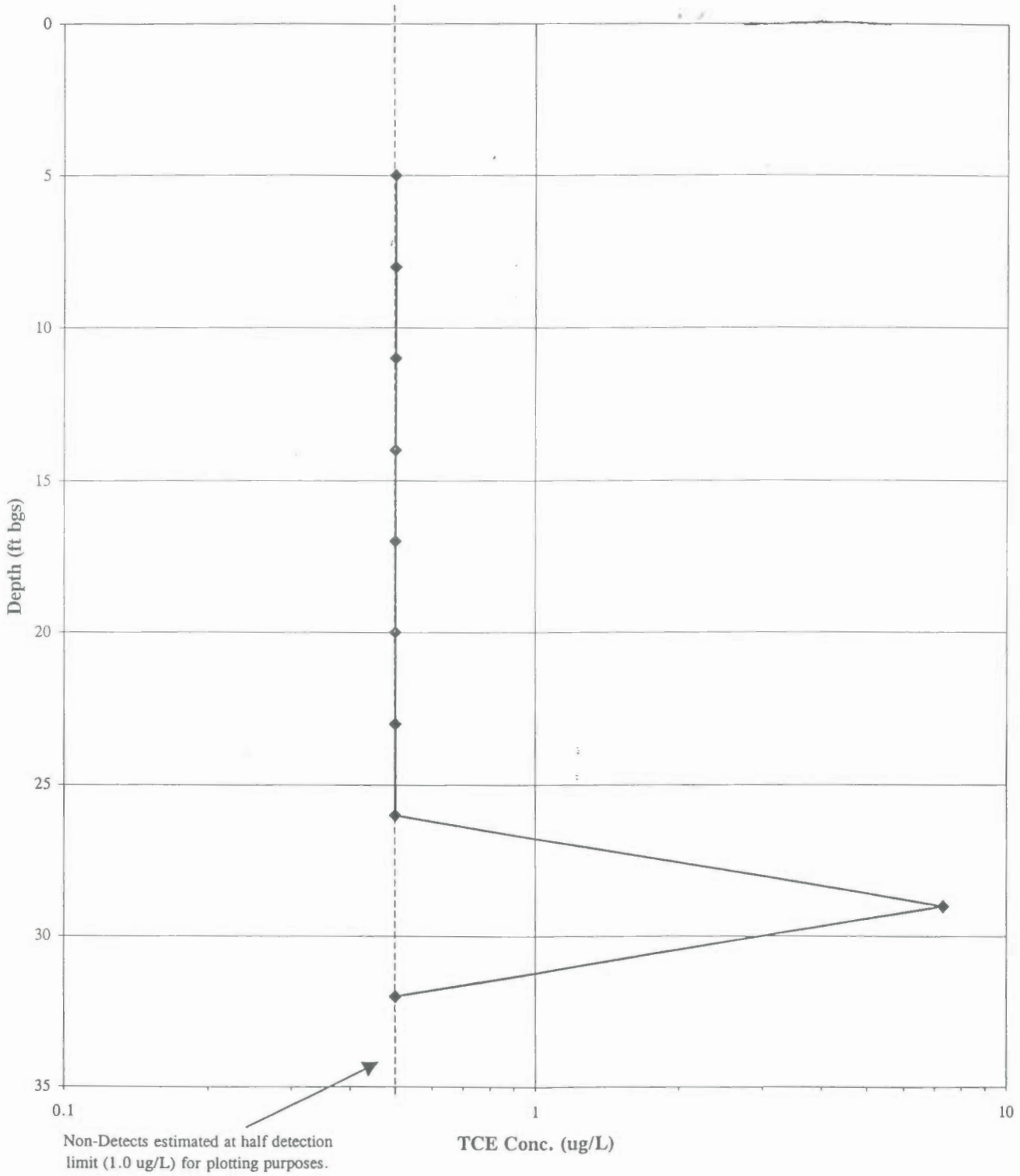


Non-Detects estimated at half detection limit (1.0 ug/L) for plotting purposes.

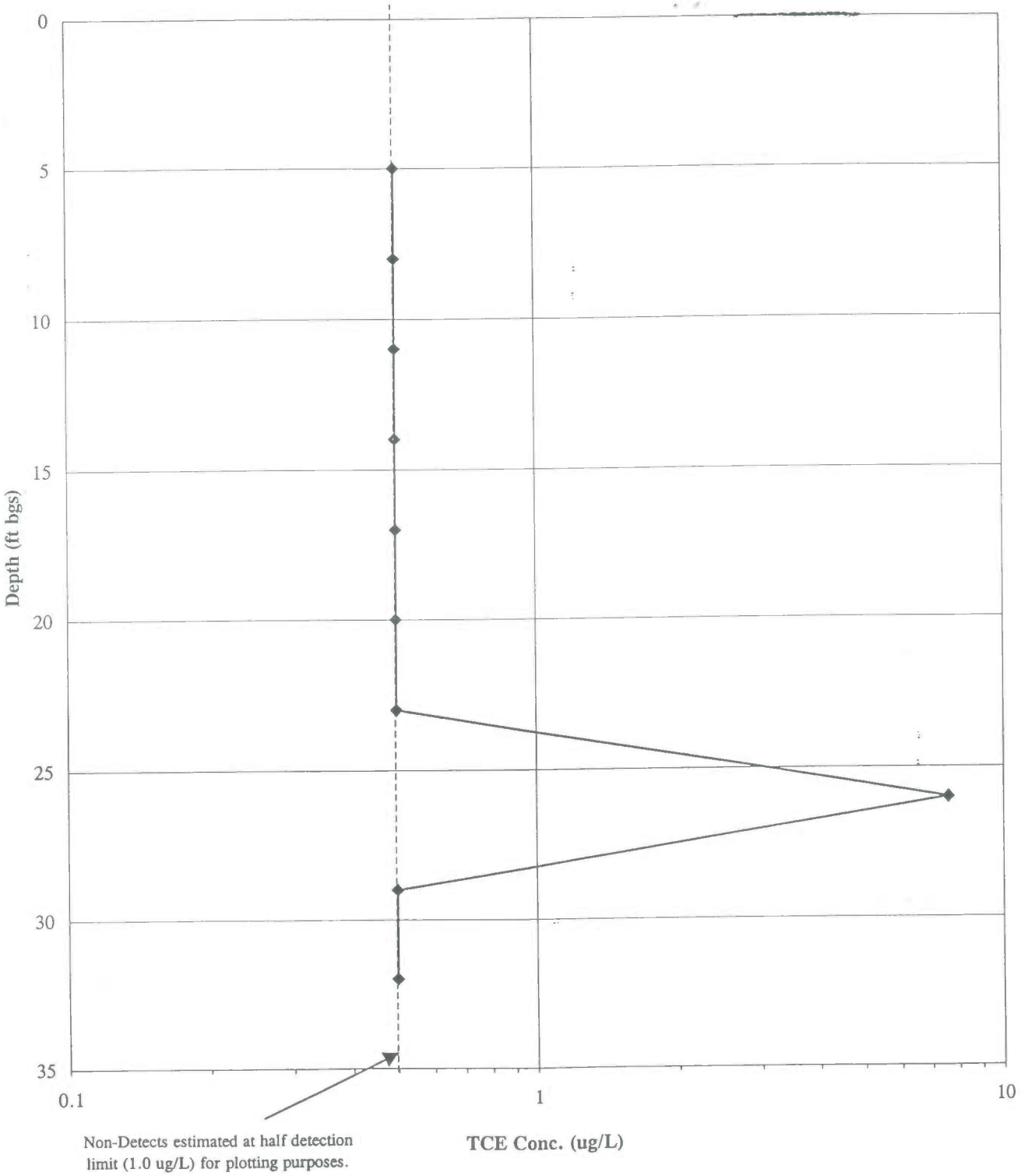
166VP002

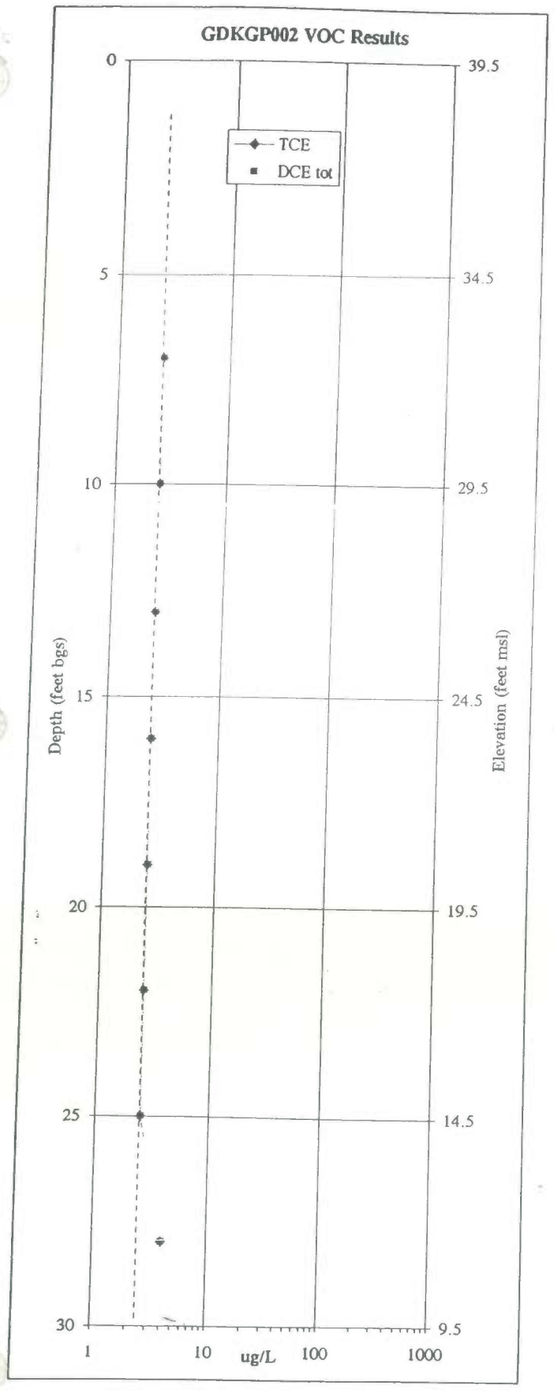

0
5
10
15
20
25
30
35
Depth (ft bgs)
0.1
1
10
TCE Conc. (ug/L)
Non-Detects estimated at half detection limit (1.0 ug/L) for plotting purposes.

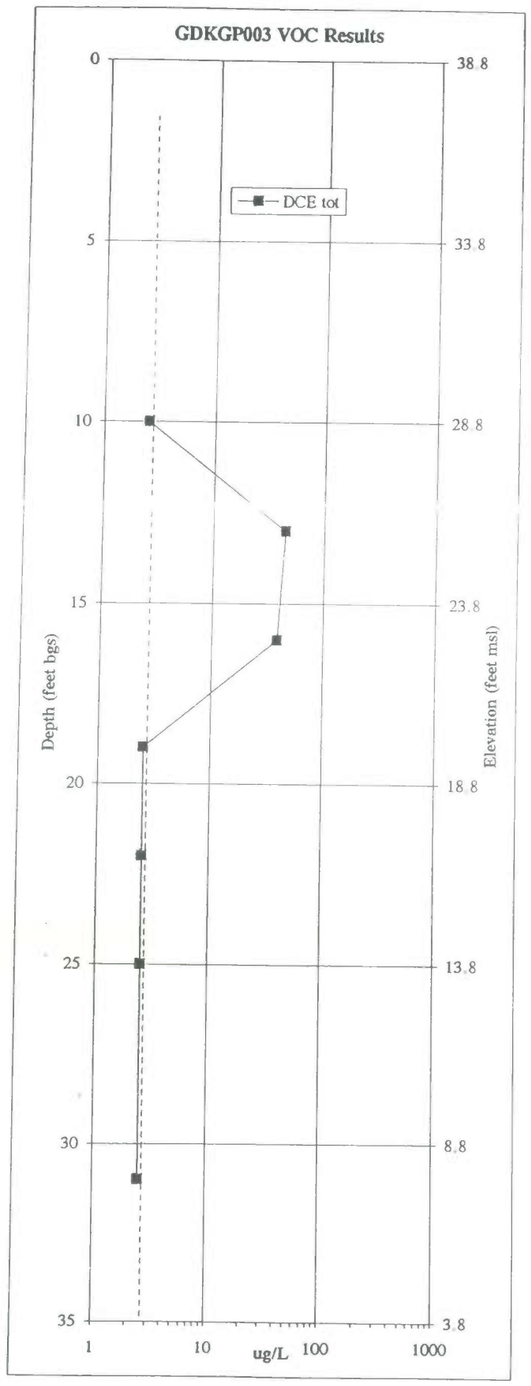
166VP001

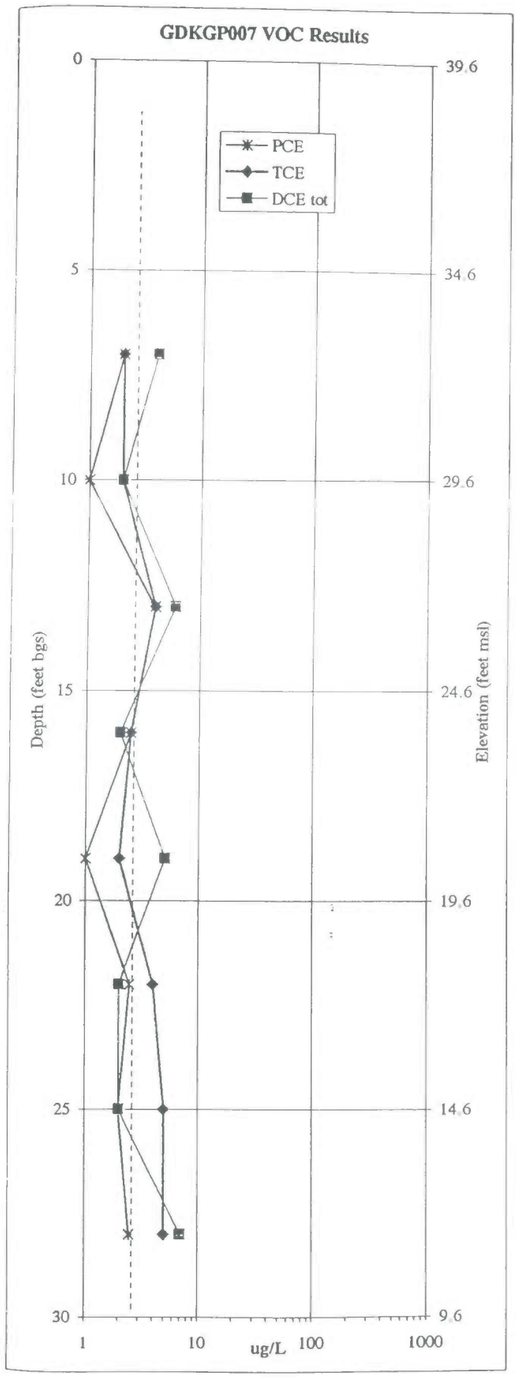

0
5
10
15
20
25
30
35
Depth (ft bgs)
0.1
1
10
TCE Conc. (ug/L)
Non-Detects estimated at half detection limit (1.0 ug/L) for plotting purposes.

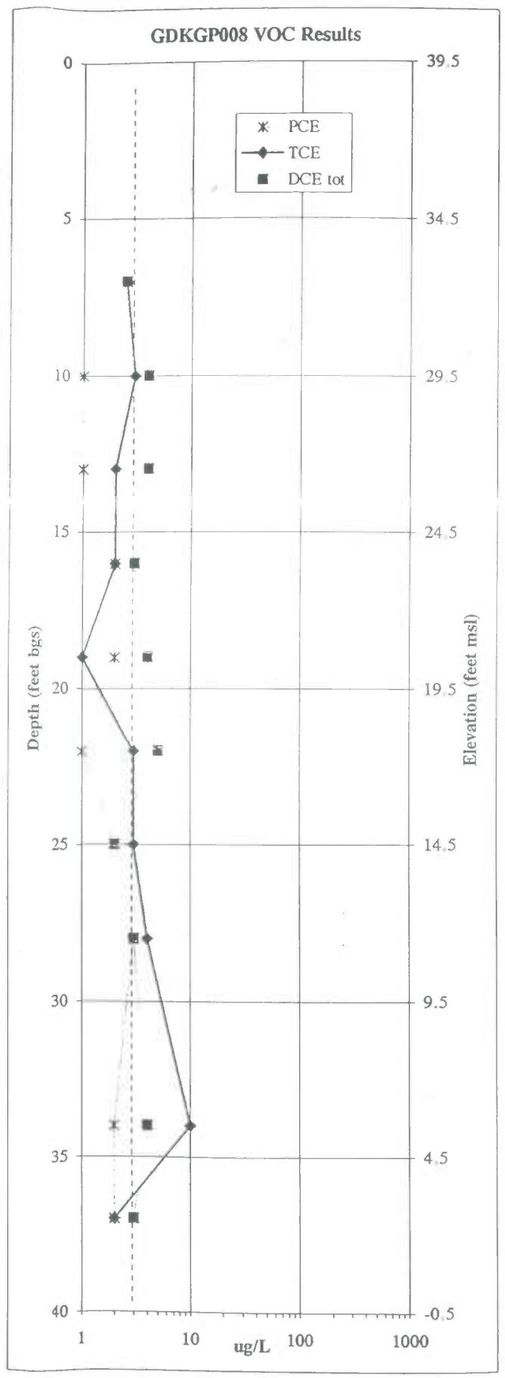
166VP004

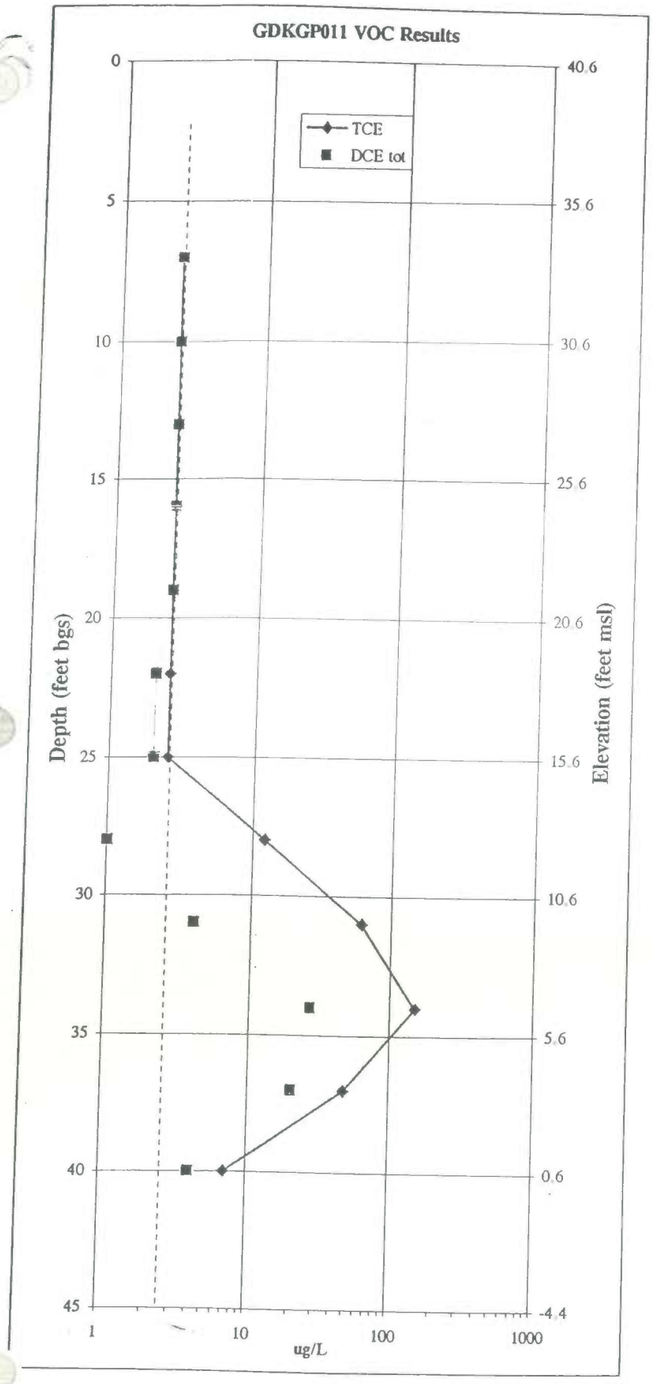

0
5
10
15
20
25
30
35
Depth (ft bgs)
0.1
1
10
TCE Conc. (ug/L)
Non-Detects estimated at half detection limit (1.0 ug/L) for plotting purposes.

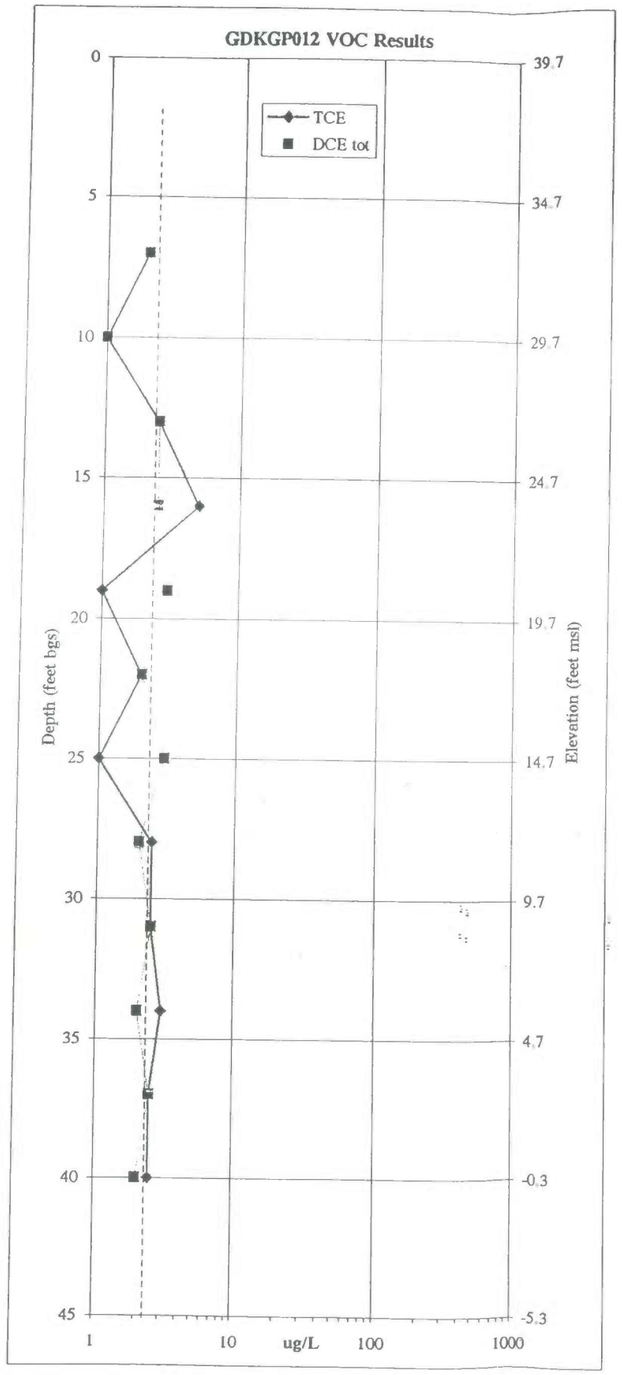

GDKGP002 VOC Results
TCE
DCE tot
Depth (feet bgs)
Elevation (feet msl)
0
5
10
15
20
25
30
39.5
34.5
29.5
24.5
19.5
14.5
9.5
1
10
100
1000
ug/L

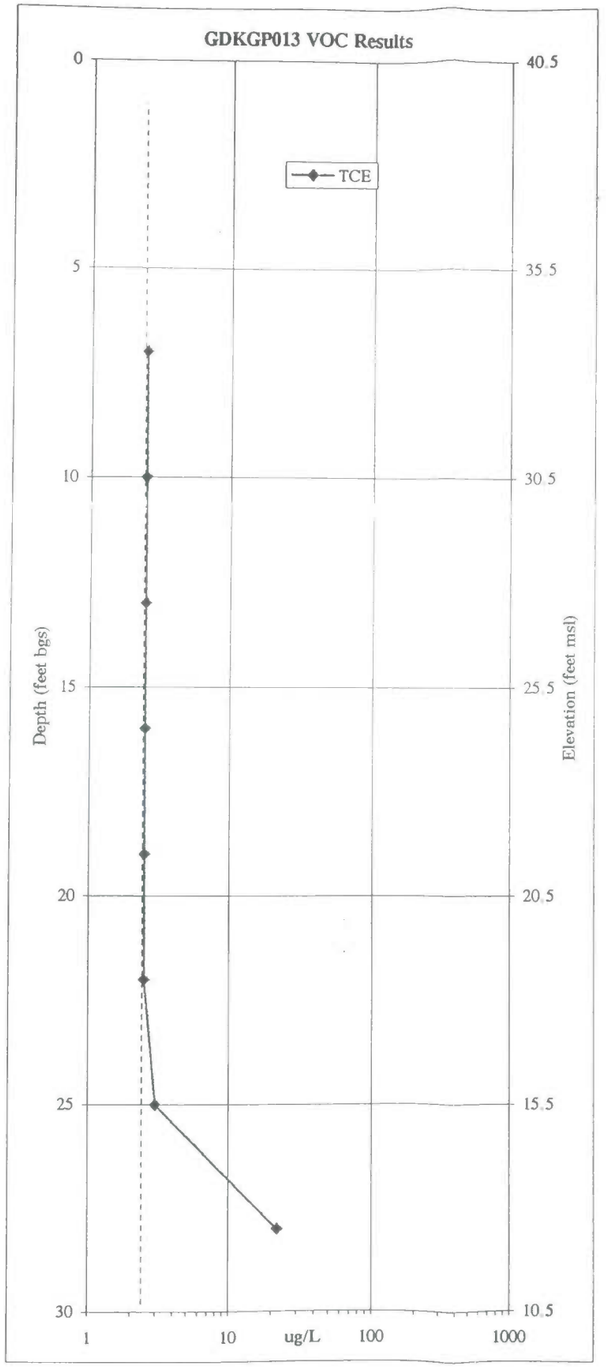

GDKGP003 VOC Results
DCE tot
Depth (feet bgs)
Elevation (feet msl)
0
5
10
15
20
25
30
35
38.8
33.8
28.8
23.8
18.8
13.8
8.8
3.8
1
10
100
1000
ug/L

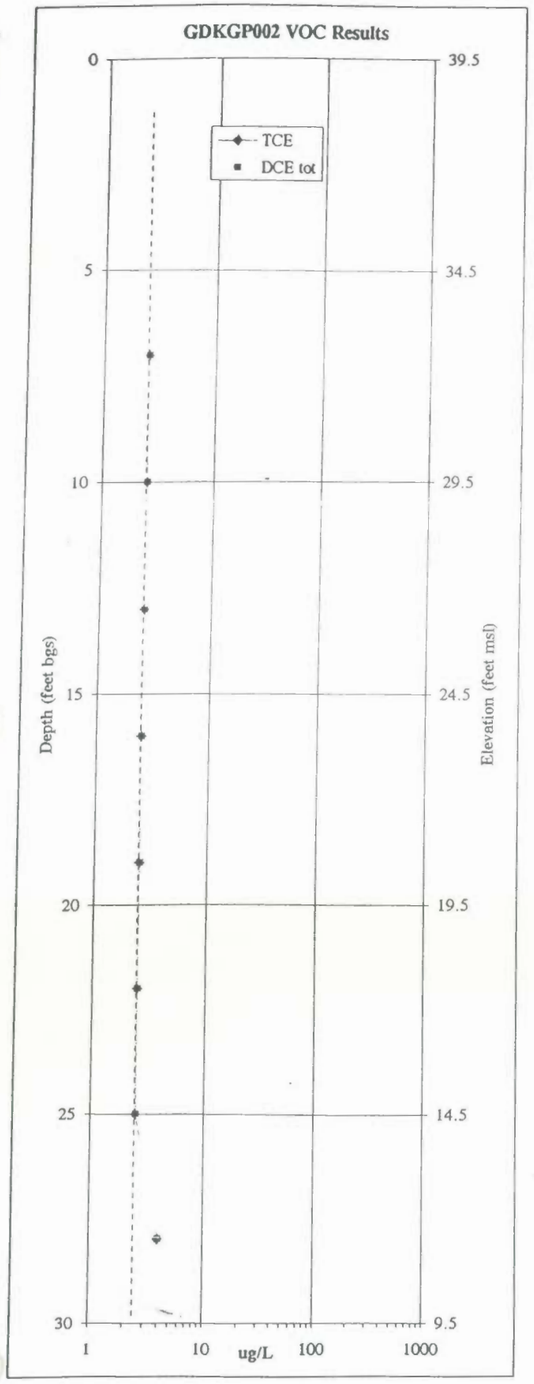

GDKGP007 VOC Results
PCE
TCE
DCE tot
Depth (feet bgs)
Elevation (feet msl)
0
5
10
15
20
25
30
39.6
34.6
29.6
24.6
19.6
14.6
9.6
1
10
100
1000
ug/L

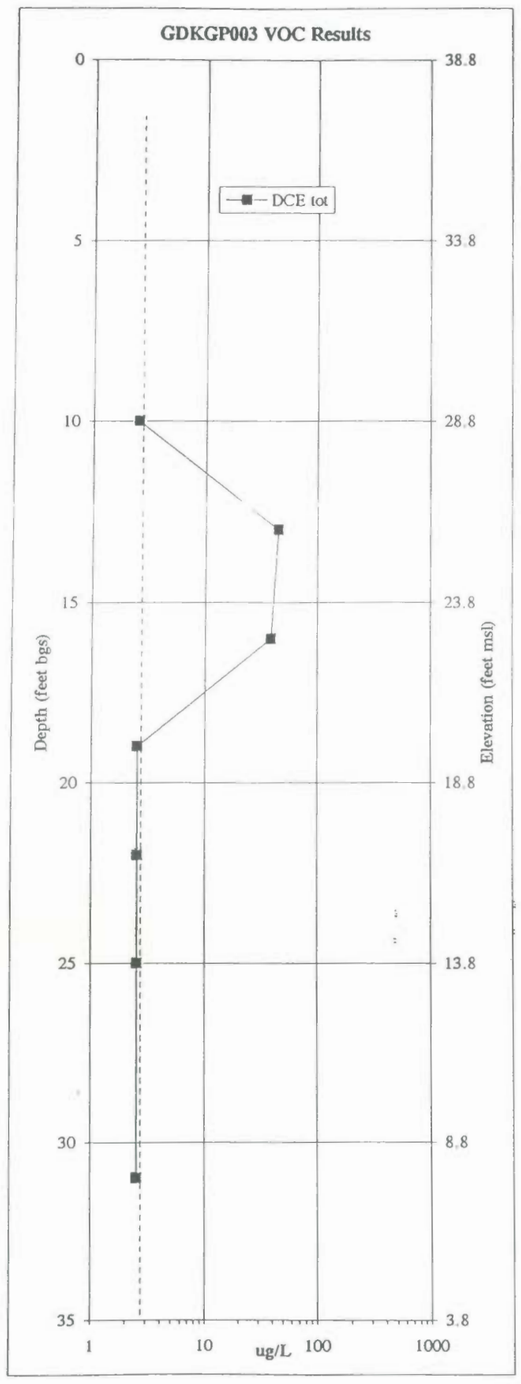

GDKGP008 VOC Results
PCE
TCE
DCE tot
Depth (feet bgs)
Elevation (feet msl)
0
5
10
15
20
25
30
35
40
39.5
34.5
29.5
24.5
19.5
14.5
9.5
4.5
-0.5
1
10
100
1000
ug/L

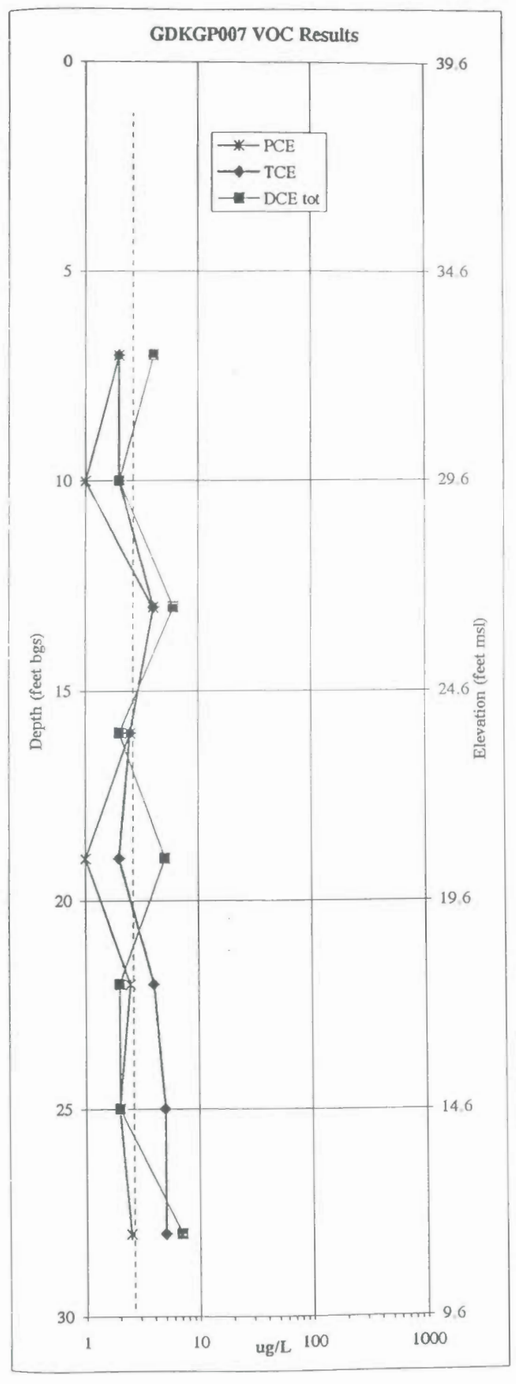

GDKGP011 VOC Results
TCE
DCE tot
Depth (feet bgs)
Elevation (feet msl)
0
5
10
15
20
25
30
35
40
45
40.6
35.6
30.6
25.6
20.6
15.6
10.6
5.6
0.6
-4.4
1
10
100
1000
ug/L

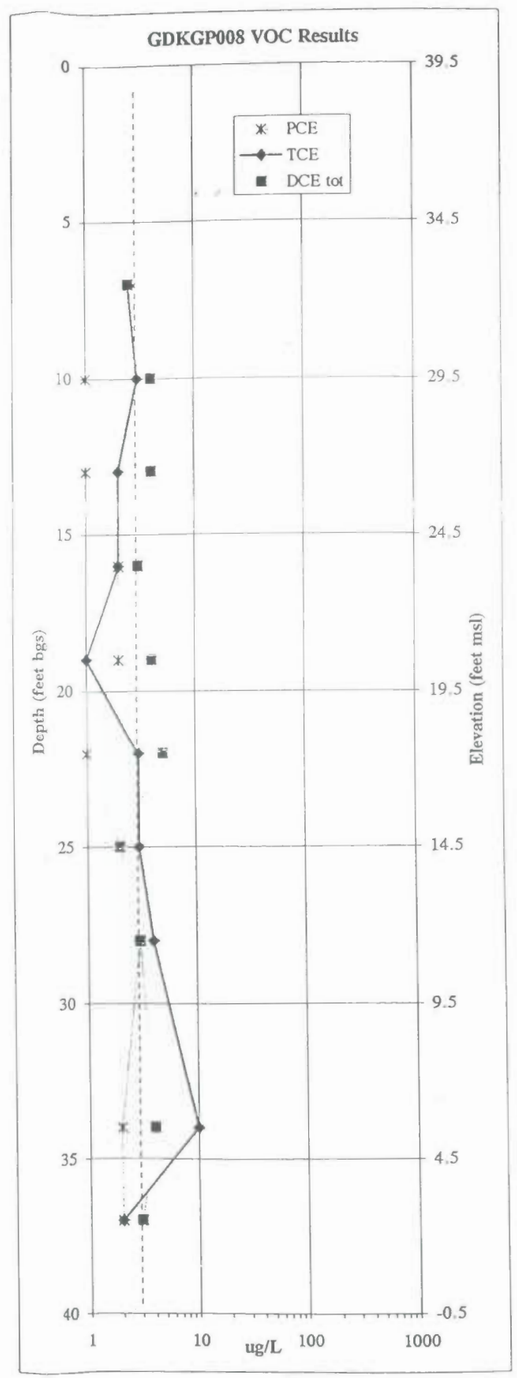

GDKGP012 VOC Results
TCE
DCE tot
Depth (feet bgs)
Elevation (feet msl)
0
5
10
15
20
25
30
35
40
45
39.7
34.7
29.7
24.7
19.7
14.7
9.7
4.7
-0.3
-5.3
1
10
100
1000
ug/L


GDKGP013 VOC Results
TCE
Depth (feet bgs)
Elevation (feet msl)
0
5
10
15
20
25
30
40.5
35.5
30.5
25.5
20.5
15.5
10.5
1
10
100
1000
ug/L


GDKGP002 VOC Results
TCE
DCE tot
Depth (feet bgs)
Elevation (feet msl)
0
5
10
15
20
25
30
39.5
34.5
29.5
24.5
19.5
14.5
9.5
1
10
ug/L
100
1000


GDKGP003 VOC Results
DCE tot
Depth (feet bgs)
Elevation (feet msl)
0
5
10
15
20
25
30
35
38.8
33.8
28.8
23.8
18.8
13.8
8.8
3.8
1
10
ug/L
100
1000


GDKGP007 VOC Results
PCE
TCE
DCE tot
Depth (feet bgs)
Elevation (feet msl)
0
5
10
15
20
25
30
39.6
34.6
29.6
24.6
19.6
14.6
9.6
1
10
ug/L
100
1000


GDKGP008 VOC Results
PCE
TCE
DCE tot
Depth (feet bgs)
Elevation (feet msl)
0
5
10
15
20
25
30
35
40
39.5
34.5
29.5
24.5
19.5
14.5
9.5
4.5
-0.5
1
10
ug/L
100
1000

2.3.3 Groundwater Flow Direction

Groundwater levels were measured on March 6, 1998, 16 shallow and 13 deep wells at the Naval Annex and seven shallow and six deep wells east and west of the interstate outside the annex boundary. All wells were first vented and allowed to equilibrate to atmospheric pressure. Water levels were collected within a two-hour period.

Groundwater elevations in the shallow wells represent the water table surface in the surficial aquifer, as shown on Figure 2-7, a piezometric map. High groundwater elevations in the northwestern portion of the annex indicate the presence of a local recharge zone near well 166001. Groundwater flows radially from this high, although its western extent was not defined during this investigation. The presence of the interstate roadcut, which lies approximately 10 feet topographically lower than the annex to the west and 6 feet lower than the land to the east, creates a discharge zone along its axis east of the annex boundary. Groundwater originating east of the interstate flows west toward it before migrating northwest along the interstate axis. Groundwater originating from the annex flows northeast to east toward it before flowing northwest along its axis. The potentiometric low at the interstate is a result of the stormwater sewer system installed as a part of the interstate construction (see Section 10.5.5).

Figure 2-8 depicts the potentiometric contours of the lower portion of the surficial aquifer. The contour pattern for the deep well groundwater elevations is similar, but more subdued than the shallow wells pattern. Groundwater flows southeast to northeast from the annex toward the interstate, where it discharges to the storm sewer system. On the interstate's eastern side, groundwater flows west toward it before discharging to the storm sewer system.

2.3.4 Vertical Hydraulic Gradient

Vertical hydraulic gradients were calculated in the surficial aquifer at 15 shallow/deep well pairs from March 6, 1998 groundwater elevation data. Calculations were made by dividing the

difference between groundwater elevations in shallow and deep well pairs by the vertical distance between the bottom of each respective well screen. Positive values indicate downward vertical gradients, whereas negative values indicated an upward vertical gradient. Table 2.6 lists each well pairs calculated vertical hydraulic gradients.

Vertical gradients at three of the four well pairs near the interstate indicate an upward hydraulic gradient. All other vertical gradients at study area well pairs were slightly downward, except for well pair 002, which was slightly upward.

The magnitude of the vertical gradients at locations away from the interstate were small, indicating that groundwater flow in these areas is primarily horizontal. The magnitude of the vertical gradients (upward) near the interstate were somewhat higher, indicating a greater vertical component to the groundwater flow. The magnitude of the upward vertical gradient along the interstate increases along the interstate in the northerly direction. The upward vertical gradient is slightest at the 018 well pair and increases to the north at the 017 and 016 well pairs.

A flow net based on water level measurements from shallow and deep monitoring wells is portrayed on the A-A' profile (Figure 2-5). An upward vertical gradient is present near the interstate; at other locations, the gradient is horizontal or downward.

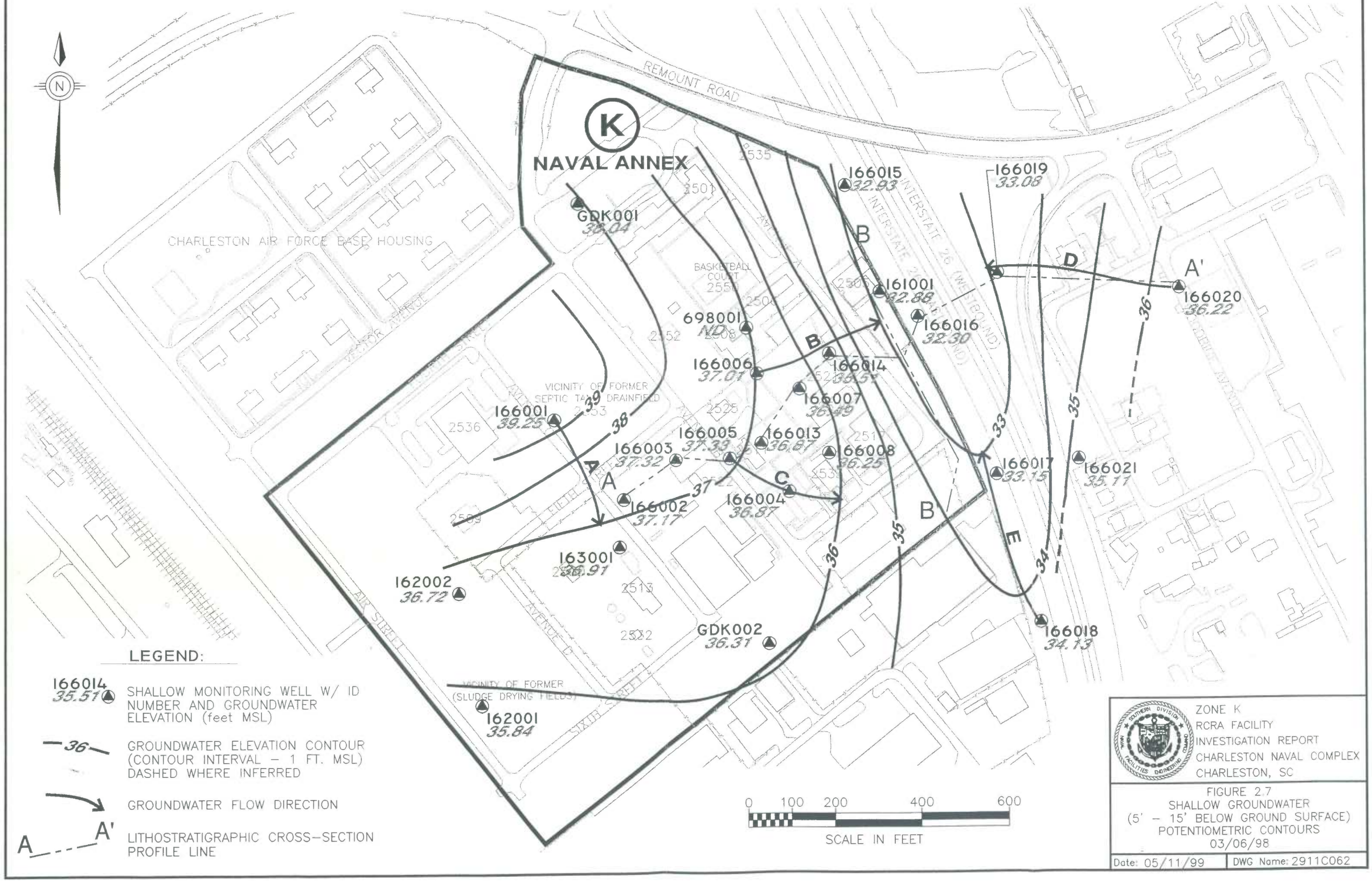


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FIGURE 2.7
SHALLOW GROUNDWATER
(5' – 15' BELOW GROUND SURFACE)
POTENTIOMETRIC CONTOURS
03/06/98

Date: 05/11/99 | DWG Name: 2911C062

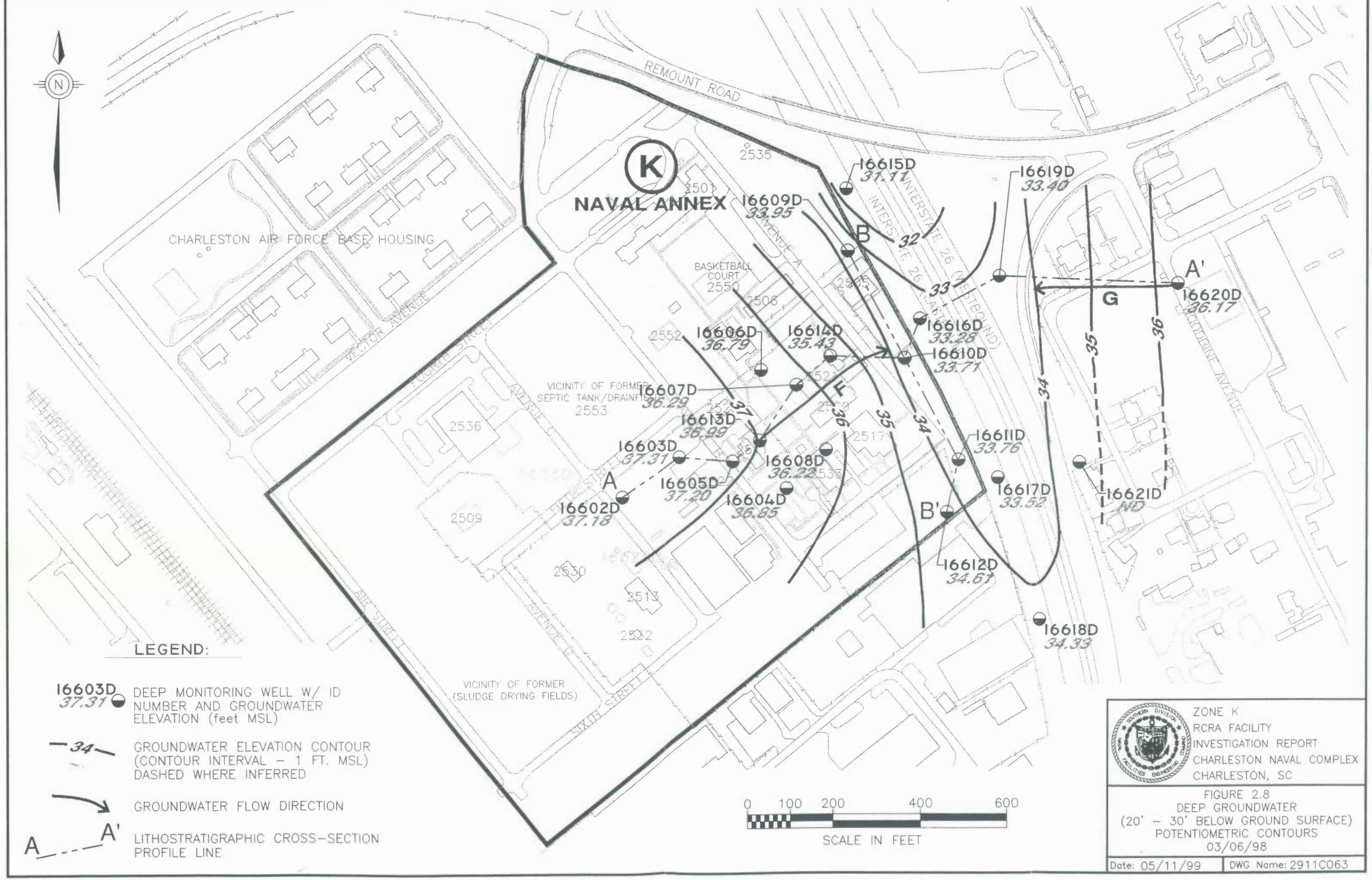

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FIGURE 2.8
DEEP GROUNDWATER
(20' – 30' BELOW GROUND SURFACE)
POTENTIOMETRIC CONTOURS
03/06/98

Date: 05/11/99 | DWG Name: 2911C063

Table 2.6
Vertical Hydraulic Gradients at Naval Annex
March 6, 1998

Well Pair	Shallow Well GW Elev. (ft msl)	Deep Well GW Elev. (ft msl)	GW Elev. Diff (ft msl)	Vertical Dist. (ft)	Vertical Hyd. Gradient
166002 and 02D	37.17	37.18	0.01	18.0	-0.0005
166003 and 03D	37.32	37.31	0.01	20.6	0.0005
166004 and 04D	36.91	36.89	0.02	19.0	0.001
166005 and 05D	37.33	37.20	0.13	17.0	0.008
166006 and 06D	36.96	36.79	0.17	18.0	0.009
166007 and 07D	36.49	36.08	0.41	19.0	0.021
166008 and 08D	36.25	36.22	0.03	21.0	0.001
166013 and 13D	37.14	37.07	0.07	19.9	0.004
166014 and 14D	35.51	35.43	0.08	17.7	0.004
166015 and 15D	32.93	31.11	1.82	12.4	0.148
166016 and 16D	32.30	33.28	0.98	13.5	-0.073
166017 and 17D	33.15	33.52	0.37	13.6	-0.027
166018 and 18D	34.13	34.33	0.20	13.7	-0.014
166019 and 19D	33.08	33.40	0.32	10.0	-0.032
166020 and 20D	36.22	36.17	0.05	15.0	0.003
166021 and 21D	35.11	31.73	Deep well potentiometric surface reflective of top of Ashley Formation rather than base of water table aquifer.		

Note:
For the vertical hydraulic gradient, a positive number indicates potential for downward flow; a negative number indicates potential for upward flow.

2.3.5 Horizontal Hydraulic Gradient

The horizontal hydraulic gradient (i) is a measurement of the change in hydraulic head (Δh) (i.e., change in groundwater elevation) at two points over the distance between them (Δx). It is a dimensionless value and is generally used to quantitatively determine the magnitude of groundwater flow in a given region.

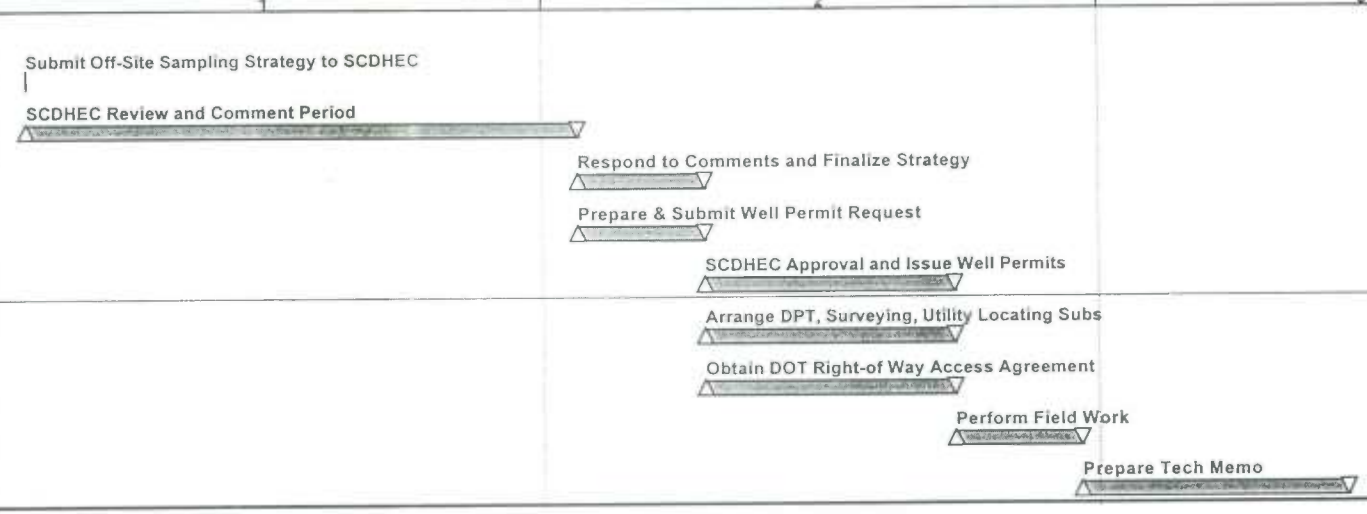
Because the well locations for the Naval Annex RFI were based solely on SWMU and AOC locations and historical land uses, few monitoring wells are actually located along groundwater flowpaths from one another. As a result, horizontal hydraulic gradients were calculated along several representative groundwater flowpaths, presented in Figure 2-7 (labeled "A" through "E") and Figure 2-8 (labeled "F" and "G"). The results are presented in Table 2.7.

Table 2.7
Horizontal Hydraulic Gradients

Flowpath	Δh (ft)	Δx (ft)	i
Shallow Wells			
A	2.25	275	0.0082
B	4.01	315	0.0127
C	1.33	285	0.0047
D	3.22	435	0.0074
E	1.13	410	0.0028
Deep Wells			
F	2.99	365	0.0082
G	2.17	335	0.0065

In general, the horizontal hydraulic gradient across the water table is greater in the northeastern portion of the annex along the interstate boundary. This is largely a function of the topographic relief related to the interstate roadcut. The range in horizontal hydraulic gradients calculated for the deep well groundwater flowpaths is smaller than that of the shallow wells. Given the relative uniformity of the groundwater flow pattern in Figure 2-8, the hydraulic gradient along the bottom of the surficial aquifer appears fairly consistent at the site.

Task	Original Duration
00001	0
00011	30
00021	7
00031	7
00041	14
00051	14
00061	14
00071	7
00081	14



Zone K Off-Site Groundwater Sampling Schedule

Charleston SC

ENSAFE